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By Shujie Chang

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RAPID RUNWAY REPAIR (RRR) TECHNIQUES: A SYSTEMS ANALYSIS

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The final results showed that the best RRR systems are asphalt blocks, fiberglass-reinforced plastic (FRP) mats, and FRP foldable mats. These repair techniques possess the desirable advantages in a RRR system. They are fast, simple, and cost effective, and extensive training is not required.

This study was conducted methodically and each phase was carefully thought out. It reflects the opinions of the author and leading RRR experts. This analysis is not intended to make the decision of which RRR system to implement; it is merely a tool to clearly state the procedures, factors, and rationale that are used to make a decision.

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13. ABSTRACT *(Maximum 200 words)*

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This study was conducted methodically and each phase was carefully thought out. It reflects the opinions of the author and leading RRR experts. This analysis is not intended to make the decision of which RRR system to implement; it is merely a tool to clearly state the procedures, factors, and rationale that are used to make a decision. Keywords

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INTRODUCTION

This report examines and analyzes nine rapid runway repair (RRR) techniques that are currently available. It uses the systems analysis approach and applies this approach to certain decision problems for choosing a RRR technique. Systems analysis is a philosophy, a concept, a way of looking at a set of problems. It is an analytic inquiry designed to help decision makers identify a preferred choice among possible alternatives. The emphasis is on the clarification of objectives, on the search for alternatives, on explicitness, on recognition of uncertainty, and on the use of quantitative models.

The scenario for this analysis is set for a fixed base in Europe. This analysis is designed to help the Naval Facilities Engineering Command (NAVFAC) examine the RRR alternatives available and analyze their overall implications for airfield operations in Europe. It leans heavily on the use of expert opinion and human judgment. The basic idea is to break a complex problem into component parts, work separately on these parts, and then put the parts together where the implications for the final decision are clearly specified. It must be stressed that this analysis is for use as a decision making tool only, it is not the decision maker.

BACKGROUND

In the event of hostilities involving the United States, the U.S. Naval airfields are critical assets for maritime patrol operations, tactical fleet resupply, and combat support mission aircraft operations. Damage to airfield pavements from sophisticated enemy munitions threatens sustained aircraft sorties until the airfield is repaired. Therefore, it is essential that the Naval Construction Force (NCF) have a RRR capability to restore the airfield's launch and recovery operations.

Over the past 15 years, the United States and other Northern Atlantic Treaty Organization (NATO) nations have conducted extensive research toward developing enhanced RRR capabilities (materials, equipment, and techniques). Several of these capabilities have been tested successfully and fielded by various services. The NCF is currently trying to determine the best RRR technique available at a fixed base that can be tailored toward their equipment and manpower allotment.

Because there are many factors and philosophies involved, difficulties may arise in choosing the best RRR technique. Often the best alternative will vary, depending on the concerned parties. Therefore, a systematic approach must be used that focuses on solving a complex problem by tying together the pertinent details in a logical manner.

PROBLEM DEFINITION

The NCF currently does not have a defined acceptable RRR technique to repair damage to airfield runway pavements caused by enemy munitions. Naval airfields are extremely vulnerable to enemy attack in any conflicts involving the United States. The enemy can inflict severe damage to airfield runways with sophisticated munitions designed to crater and spall a runway. To restore airfield operations, the NCF must be able to perform the associated tasks to quickly repair a runway.

GOAL AND OBJECTIVES

The overall goal of this analysis is to provide a method for NAVFAC to analyze and select the best RRR techniques available to restore an airfield to operational status following enemy attack. The objectives are to present feasible alternatives to the problem and to provide NAVFAC with all the relevant information necessary for decision making through a logical, systematic, and consistent approach.

ALTERNATIVES

Nine RRR alternative techniques were researched and considered as suitable. These alternatives were analyzed based on previous and current research data gathered from the United States Air Force, Army, and Navy, and the Royal Engineers from the United Kingdom. Each alternative is examined and evaluated, in relation with one another, based on the defined criteria (evaluation factors). It is assumed that the decision maker has all power over men, money, and materials, therefore implementation factors are not considered. The nine alternatives are summarized below and Table 1 shows the advantages and disadvantages of each repair system.

Fiberglass-Reinforced Plastic (FRP) Mats

FRP mats are made of two to three plies of 4020 style fiberglass impregnated with polyester resin (see Figure 1). The traditional mat dimensions are approximately 60 square feet; however, mats of other sizes can also be made. The mats, which are not transportable due to their dimensions, must be fabricated at the site. If the mat size is not large enough or too large, two mats can be glued together or one mat can be cut with a circular saw to the desired dimensions.

The general procedures for FRP mat crater repair are:

1. Backfill the crater with existing debris to within 18 to 24 inches of pavement surface.

2. Fill the crater with well-graded crushed rock up to 2 to 4 inches above the pavement surface and compact it to pavement level with a vibratory roller.

3. Tow FRP mat over repair and bolt to pavement surface.

4. Construct a polymer concrete ramp on the mat's leading edges to facilitate tailhook operations.

This repair method assumes that the crater does not contain standing water, and that the debris backfill is reasonably firm (California Bearing Ratio of 3 to 5). When standing water is present inside the crater, the crater should be backfilled with choked-ballast rock to within 4 to 6 inches of the pavement surface. Crushed rock is then filled to 2 to 4 inches above the pavement surface and compacted level with the pavement surface.

Bolt-Together FRP Panels

Bolt-together FRP panels are made of three plies of 4020 style fiberglass impregnated with polyester resin (see Figures 2 and 3). The basic panel dimensions are 18 feet long by 6.67 feet wide by 3/8 inch thick and weigh approximately 300 pounds per panel. The panels are air transportable and can be bolted together at the site to form the desired dimensions.

The repair procedures for using bolt-together FRP panels are identical to the FRP mat crater repair techniques.

Foldable FRP Mats

Foldable FRP mats are made of two plies of 4020 style fiberglass impregnated with polyester resin (see Figures 4 and 5). The mats consist of a number of panels which are joined along the edges with fiberglass hinges and impregnated with a flexible polyurethane. The flexible joints allow the mat to be folded, thereby allowing the mats to be air transportable. Foldable FRP mats can also be glued together or cut to make larger or smaller patches if necessary.

The repair procedures for using foldable FRP mats are identical to the FRP mat crater repair techniques.

Precast Concrete Slabs

This repair, which was developed by the United States Air Force Europe (USAFE), uses precast concrete slabs. The slabs, which are made of Portland cement concrete, measure 2 meters by 2 meters by 15 centimeters thick and have reinforcing strips along the squared top edges (see Figure 6). The general procedures for this repair are to:

1. Remove all the debris from the crater.

2. Saw and break away the concrete around the crater perimeter to ensure a square or rectangular crater shape.

3. Fill the crater with ballast rock up to 10 inches from the pavement surface and overlay with a 4- to 5-inch-thick layer of uniform 3/8-inch sized gravel as a leveling course.

4. Level the gravel with a screed beam to about 4 inches below the pavement surface.

5. Place the precast concrete slabs onto the leveling course and compact using a roller.

Precast Asphalt Concrete Block

This crater repair technique uses asphalt concrete blocks that are preformed and precompacted. The asphalt concrete block dimensions are 24 inches wide by 24 inches long by 3 to 4 inches thick (see Figures 7 and 8). The general procedures for this repair are:

1. Backfill the crater with existing debris to within 18 to 24 inches of the pavement surface.

2. Fill the crater with crushed rock and compact to within 2 to 3 inches of the pavement surface, depending on the block thickness.

3. Place asphalt concrete blocks over the crater.

4. Heat asphalt blocks with an infrared heater, level, and compact asphalt to form a flush repair.

Magnesium Phosphate

This repair method uses a specially formulated non-shrinking grout designed to penetrate the voids in the selected aggregate fill. The grout mixer system is shown in Figure 9. The magnesia phosphate cement blended with special fillers and accelerators or retarders provides a controlled high early-strength pavement under different weather conditions. The general procedure for this repair is to: (1) fill the crater with ballast fill (2-inch single size) and a leveling layer of graded stone (3/16 to 1-1/4 inch) up to 8 inches below the pavement surface, and (2) place a grout seal geotextile overlain by 8 inches of a deep flood grouted layer of 5/8- to 7/8-inch crushed rock. After setting, the area is ready for traffic.

Crushed Rock

The crushed rock repair requires a very high quality, well-graded crushed rock. The general procedures for crushed rock repair are:

1. Backfill existing debris up to 24 inches from the pavement surface.

2. Fill crushed rock up to the pavement surface and compact (in several layers). Since no foreign object damage (FOD) covers will be used for this repair, it is extremely crucial that the crushed rock be of proper gradation and compacted to specifications (usually 100 percent of maximum laboratory density as specified by ASTM Modified Proctor Test) (see Figure 10).

Polyurethane Cap

This repair method uses a polyurethane grout designed to penetrate voids in the selected aggregate base. The polyurethane is blended with accelerators to control the setting time to provide a rapid setting high-strength polymer concrete surface (see Figure 11). The general repair procedures are:

1. Backfill and level existing debris to 8 to 10 inches below pavement surface.

2. Fill with uniform size gravel up to pavement surface; apply polyurethane polymer concrete and allow it to percolate down through the gravel to the debris.

3. Continue filling the crater until percolated concrete is even with pavement surface; and allow approximately 5 minutes for setting until trafficking.

AM-2 Aluminum Matting

AM-2 is an aluminum matting used primarily to surface runways, taxiways, and parking areas for expeditionary airfields. AM-2 is a fabricated aluminum panel, 1-1/2 inches thick, that consists of a hollow, extruded, one-piece main section with extruded end connectors welded at each end (Figure 12). Each panel is 12 feet long by 2 feet wide and weighs 144 pounds. The panels are air transportable and can be assembled at the site to form the desired dimensions.

The repair procedures for using AM-2 matting are identical to the FRP mat crater repair techniques.

CRITERIA

A number of criteria important in RRR will be used as evaluation factors. These criteria will be evaluated with respect to their role in attaining the overall goal. Each criterion will be measured and used for comparison of alternatives. These criteria are listed and explained below:

1. Equipment Intensiveness: The NCF plans to use the Advanced Base Functional Component (ABFC) P-36 equipment for most of its crater repair tasks. It is important that the RRR technique chosen does not overtax the available equipment in regard to pieces of equipment, power output required, and working time.

2. Dependency: Due to potentially harsh conditions and the possibility of untrained personnel in the working environment, various tasks within the repair may not be performed to acceptable levels. It is important that the repair technique chosen does not completely depend on proper performance of all tasks or subtasks to ensure a degree of success.

3. Need for Dedicated Equipment: Specialized or dedicated equipment may be needed for a given repair technique. The more dedicated equipment that is needed the more undesirable the repair method becomes.

4. Operational (under wide temperature range): During the repair, conditions of extreme cold or heat may exist. The repair technique chosen should be deployable and operational under the widest temperature range.

5. Labor Intensiveness: During the repair, manual labor may be scarce. The repair technique chosen must not overtax the personnel in regard to number and labor intensiveness.

6. Complexity: Trained personnel may not be available during the repair. Therefore, any available personnel such as clerks and cooks may be used to perform RRR. The repair technique chosen must be kept as simple as possible. Complexity can result in a greater potential for unforeseen difficulties and errors.

7. Peacetime Usage: It is desirable that the crater repair technique chosen (equipment and materials) has peacetime applications. This would allow the equipment and materials to be used routinely and productively during peacetime, thereby placing less emphasis on shelf life, cost, and training.

8. Structural Strength: All repair techniques under analysis have a limited number of aircraft sorties that they can support before maintenance is required. The more sorties that the chosen repair technique can support in between maintenance periods, the more desirable.

9. Maintenance Difficulty: Since all repair techniques are assumed to need maintenance periodically, it is important to keep this task simple. A repair method that is easy to deploy initially, but difficult to maintain, may not be desirable.

10. Shelf Life: If the material shelf life is too short, it may not be usable when needed. It is important that the material keep its properties during long-term storage.

11. Cost: The RRR technique chosen may demand dedicated equipment and specialized materials. Acquiring these items requires substantial outlays of capital. It is desirable to keep cost to a minimum.

12. Initial Repair Time: The most important factor in RRR is to restore the airfield to operational status in the shortest time possible. Therefore, the time to conduct a RRR repair should be kept to a minimum.

13. Utility: Runway crater repair is only a part of what is required to restore an airfield to operational status. Other tasks such as taxiway repair, spall repair, and ramp construction are also necessary to restore an airfield. It would be beneficial if the RRR technique chosen has applications for tasks other than runway crater repair.

14. Storage: Different materials and/or equipment have different storage requirements. It is important that the materials and equipment can be stored in limited space and do not require special facilities or containers.

15. Operational (under wide range of aircraft types): The airfield being repaired may have to support a wide spectrum of aircraft. The repair method chosen should be able to handle all types of aircraft ranging from cargo to fighter aircraft.

The criteria defined in this section were subjectively ranked and weighted using the Delphi technique. A questionnaire was sent to nine RRR experts asking for their subjective opinions regarding the relative importance of each criterion for RRR. This procedure was repeated three times, each time (after the first) the experts saw the median and 50th percentile answers from their peers. The experts were asked to provide explanations if their answers did not fall within the 50th percentile range. Table 2 shows the final criteria rankings (highest to lowest importance) and weighted values. Appendix A shows the three questionnaires that were sent out for this analysis.

STATES OF NATURE AND ASSOCIATED PROBABILITIES

The environments where the RRR system may have to operate are defined as states of nature (SN). Since the future operational environment for the alternatives involves uncertainty, an estimate of the probability of operating under a given environment must be made. The probability is a measure of the possibility of each state of nature actually occurring or being in effect when action is taken. It is assumed that the possible environments are mutually exclusive, therefore the sum of the probabilities must equal one.

Three environments were identified where the RRR system may have to operate. Their associated probabilities were derived from gathering research data and talking to leading experts from the field. The three defined states of nature are presented and summarized below:

1. State of Nature 1 (SN1) - This state of nature is based on the most probable environment the system is expected to operate under. It is expected that the weather will be dry and the temperature will range between -20 °F and 120 °F. Chemical, biological, and radiological (CBR) gas will not be present. For SN1, the probability of occurrence is estimated to be 80 percent.

2. State of Nature 2 (SN2) - This state of nature is based on the probability that the system may have to operate under wet conditions, such as a constant downpour. To predict this scenario, weather data was gathered for various

parts of Europe and examined. Analysis of this data indicates that there is a probability of 0.15 that it may rain (rain is defined as moisture constituting more than 1 millimeter) in any given 4-hour period in Europe. Therefore, for SN2 (constant downpour, no CBR gas present, temperature range between 32 °F and 120 °F), the probability of occurrence is estimated to be 15 percent.

3. State of Nature 3 (SN3) - This state of nature is based on the probability that the system may have to operate under CBR conditions. CBR threat data was difficult to obtain because some of the data are classified. To keep this document unclassified, the probability predictions were made based on information provided by experts at the Naval Civil Engineering Laboratory (NCEL). For SN3 (CBR gas present, dry conditions, temperature range between -20 °F and 120 °F), the probability of occurrence is estimated to be 5 percent.

UTILITY MEASUREMENTS

After defining and ranking the criteria, utility graphs were constructed for each criterion. This step is the prelude to measuring the utility or worth of each alternative on each criterion. Utility is defined as an alternative's value to the system based on each criterion. Utility graphs are used to graphically depict the preferences for the system.

The utility graphs are represented by a two-dimensional X-Y plot. The X-axis represents the range of performance values possible for the criterion under consideration. The Y-axis represents the range of utility values associated with various levels of criterion performance. The shape of the graph is then drawn based on preferences over a set of values for each criterion. For example (see Figure 13), the utility graph for the criterion initial repair time is an S-curve with change in curvature at 4 hours (increase in curvature after 4 hours), and 8 hours (decrease in curvature after 8 hours) on the X-axis. This indicates that for an initial repair time of from 0 to 4 hours, the value to the system is very high. The increase in repair time inside the 4-hour range (i.e., from 2 hours to 3 hours) is not seen as critically detrimental. However, any increase in repair time after the 4-hour range is seen as a major setback, thereby justifying the rapid decrease in utility in that range. After the 8-hour range, the curve decreases in slope indicating that the repair method after 8 hours is seen as a semipermanent repair and additional decreases in time are not significant to the emergency repair system. Utility graphs were constructed for all criterion under all three states of nature through a brainstorming session (see Appendix A for brainstorming definition) by several NCEL experts (personnel who have extensive background in RRR) (see Figures 13 through 57 for utility graphs).

COMPARISON OF ALTERNATIVES

After constructing the utility graphs, specific data regarding each alternative were plotted onto the utility graphs to obtain utility values. For example, under the FRP mat alternative, it was determined that the mats cost about $5 per square foot. These data were plotted onto the cost utility curve and a utility value of 10 was obtained (see Figure 23). For criterion, such as labor intensiveness (see Figure 16), where there are no discrete values, subjective values were used that were obtained from a brainstorming session. A value of ten is defined as extremely labor intensive (any RRR technique that is more labor intensive is unacceptable and will not be considered). A value of zero is then considered to be ideal with very little labor required.

Once the criteria data were plotted onto the utility graphs, utility values were obtained for all alternatives under the three states of nature (see Tables 3 through 5). The weighted value for each criterion was then calculated by multiplying the utility value by its relative weight (see Tables 6 through 8). The composite utility of each alternative, under the effects of various states of nature, is determined by adding the weighted utility values of all 15 criteria (see Table 9). The decision rule for this analysis is to choose the alternative that offers the highest composite utility across the three states of nature. Table 9 also shows the final rankings obtained for each state of nature in parenthesis and the final rankings obtained for the combined states of nature. A general summary of procedures that were used for this analysis are described below:

1. The criteria outlined earlier were ranked in order of importance (using the Delphi technique) and each criterion was assigned a weighted value.

2. Utility graphs were then developed (through the consensus of several NCEL experts) for each criteria.

3. Three states of nature were defined and a probability of occurrence was assigned to each state of nature.

4. Specific data for each alternative (under three possible states of nature) were then plotted onto the utility curves to obtain utility values.

5. Weighted utility values were obtained by multiplying the values obtained in step 4 by weighted values obtained in step 1. The following equation was used:

$$WU_{nij} = U_{nij} \times W_i$$

where WU_{nij} = weighted utility for alternative n under a given criterion i and state of nature j

Unij = utility for alternative n under a given criterion i and state of nature j

Wi = weight for a given criterion i

6. The composite utility for each state of nature was obtained by summing all the weighted values for the criteria. The following equation was used:

CUnj = summation of WUnij, i = 1 to 15

where CUnj = composite utility for alternative n under state of nature j

WUnij = weighted utility for alternative n under a given criteria i and state of nature j

7. The adjusted composite utility values were obtained by multiplying the composite utility for each state of nature by the probability of occurrence for that state of nature. The following equation was used:

ACUnj = CUnj X P(SNj)

where ACUnj = adjusted composite utility for alternative n under state of nature j

CUnj = composite utility for alternative n under state of nature j

P(SNj) = probability of occurrence for state of nature j

8. The final composite utility values were obtained by adding the adjusted composite utilities for all three states of nature. The following equation was used:

FCUn = ACUnl + ACUn2 + ACUn3

where FCUn = final composite utility for alternative n

ACUnl = adjusted composite utility for alternative n under state of nature 1

ACUn2 = adjusted composite utility for alternative n under sate of nature 2

ACUn3 = adjusted composite utility for alternative n under state of nature 3

SENSITIVITY ANALYSIS

By comparing the final utility values for each alternative under the three states of nature, an alternative's sensitivity to change in the environment can be determined. The system sensitivity analysis was performed by dividing the composite utilities for state of nature 2 and 3 into the composite utilities for state of nature 1. The deviation of the resultant quotient from the ideal (a value of 1) is a direct measure of the alternative's sensitivity to change in the environment. For example, crushed rock has a final value of 0.62 for SN2 compared to SN1, and 0.99 for SN3 compared to SN1 (see Table 10). This indicates that the effectiveness of the crushed rock repair method is greatly decreased by rain, however the presence of CBR has little negative impact.

Sensitivity analysis was also performed on a criterion-by-criterion basis, rather than the "sum of criteria," to gain a more in-depth insight on what criteria are affected the most by change in the environment. Tables 11 and 12 show the results from the sensitivity analysis.

COMMENTS AND CONCLUSIONS

Nine alternative techniques for repairing bomb damaged airfields were examined and analyzed in this systems analysis. The procedures followed a systematic format that used analytic techniques to solve the problem. The analysis began by identifying and defining the problem, which is that the NCF lacks a capability to rapidly repair bomb-damaged runways. Thus, the goal is to provide the NCF with the most efficient and cost effective techniques to rapidly repair bomb-damaged runways. The alternatives were evaluated against criteria (evaluation factors) identified by experts at NCEL. The criteria were weighted based on the relative importance of each criterion in achieving the overall goal. The final step was to develop a decision rule to select the best alternative. In this analysis, the decision rule is to select the alternative which yields the highest or maximum expected utility from the criteria. This is achieved by making a decision matrix of alternatives versus a list of evaluation factors derived from the criteria for success.

The decision matrix is a good presentation of the available RRR techniques and their value as overall RRR systems in relation to each other. The following describes each alternative (with final utility values in parenthesis) and how that alternative did when subjected to the criteria (evaluation factors) outlined earlier:

1. Asphalt Blocks (5492) - Asphalt blocks scored the highest of all the alternatives. This repair technique ranked consistently high in all the categories and under all three states of nature, indicating that it was not sensitive to environmental changes. Repairs using asphalt blocks are fast, simple, and cost effective. Asphalt blocks can be easily stored, have long shelf life characteristics, and can be used for peacetime applications. They are sensitive to extreme hot temperatures and require two types of dedicated equipment (infrared heater and reclaimer). This technique is still in the research phase and as more data become available, it will be included in future editions of this report.

2. FRP Mat (5276) - The FRP mat technique ranked consistently high in most of the categories. It is a proven technique that is fast, simple, inexpensive, and has long shelf life characteristics. FRP mat performance is not affected by changes in temperature nor is it significantly affected by the presence of rain or CBR. The structural strength characteristics and maintenance requirements of the mats were rated slightly lower than most of the other techniques. Since FRP mats have minimal applications in peacetime, they were given a low rating for this category.

3. FRP Folded (5205) - The foldable FRP repair technique is almost identical to that of the FRP mat technique. The concept is basically the same with the exception that the foldable mat is air transportable. The air transportability factor has increased the mat cost, increased the complexity, decreased the structural strength, and decreased the shelf life characteristics (due to the hinges). The slightly lower scores for the folded FRP compared to the FRP mat are a result of these changes.

4. Crushed Rock (5195) - The crushed rock technique scored consistently high under SN1. For SN1, it has the second highest score behind asphalt blocks. It is a very fast, simple, and inexpensive repair technique with good peacetime applications. It is not labor or equipment intensive and is easy to maintain. However, when constant rain (SN2) was introduced into the scenario, it faltered drastically. Crushed rock repair cannot be used in rain because the rain interferes with compaction, weakens the material, and washes the fines away, thereby rendering the repair ineffective. Under dry conditions it is an excellent alternative; however, its sensitivity to environmental (rain) changes has decreased its rating from number two to four.

5. FRP Panel (5182) - The FRP panel is almost identical to the FRP mat technique. The concepts, attributes, and drawbacks are almost the same. The biggest difference is that the panels are designed to be air transported and bolted together at the site. This factor has made the panels significantly more expensive, complex, and labor intensive over the FRP mat. Lower scores were attained in these categories compared to the mat.

6. Magnesium Phosphate (5092) - Magnesium phosphate scored consistently high in the majority of the categories. It is a fast, structurally strong, and maintenance free repair technique. The problem is that it is complex and very costly. It is doubtful that this technique could be made simpler, however the cost could possibly be reduced. It has limited peacetime applications and does not operate well under extremely cold conditions. Sensitivity analysis indicates that this repair is somewhat sensitive to rain.

7. AM-2 Aluminum Matting (5089) - AM-2 matting scored consistently high in the majority of the categories. It is a proven technique that is fast and simple. AM-2 matting is easy to store, has indefinite shelf life, and is not sensitive to environmental changes. The drawbacks of AM-2 matting are that it is labor intensive, very expensive, and introduces an unacceptable roughness/bump criteria for some aircraft.

8. Polyurethane Cap (4803) - Polyurethane cap repair had a fluctuation of very high scores and very low scores. It did extremely well in the repair time, strength, labor intensiveness, and maintenance category since it is a fast, structurally strong, and maintenance free repair. However, it is the most complex and expensive of all the alternatives. It is difficult to store, has limited shelf life, and, because of high costs, has no known peacetime applications.

9. Concrete Slabs (4750) - The concrete slab technique did well in most of the categories. It is a structurally strong, easily maintained, and inexpensive repair that has good peacetime applications. It scored poorly however, because in the categories that were weighted the heaviest, it scored the least. It is a complex and very slow repair technique. It is extremely labor intensive and is heavily dependent on doing each subtask correctly.

If the decision matrix is the only tool used for making the decision, then the clear choice is asphalt blocks, with FRP mat as the second choice. Concrete blocks should not be considered at all. However, this analysis is based on judgmental data from the author and selected experts which reflect the background and experience of the author and experts. Nevertheless, the values suggest that there is a clear cut winner, although each alternative has its particular advantages and drawbacks.

The matrix suggests that asphalt block is the best solution as it has all the advantages desired in the RRR system. There are several alternatives which scored very close to each other. In this case, the determining factor should not be the overall score, but the overall score in combination with the sensitivity factor. If an alternative is extremely sensitive, then accuracy of predictions plays an even more important role in this analysis.

Other factors outside this analysis must also be considered. This analysis assumes that the scenario is at a fixed base in the NATO arena. If this is not the case, then outside factors play an even more important role. For example, if air transportability is a requirement, then only the alternatives which are air transportable can be considered, regardless of the benefits of the others.

A systems analysis has been performed on the RRR system. The analysis is based on a logical step-by-step procedure of analyzing the smallest details of each system. It reflects the opinions of the author and leading RRR experts. This analysis is not intended to make the decision of which RRR system to implement; it is merely a means, a tool for NAVFAC to use for making a decision.

The analysis was conducted methodically and each phase was carefully thought out. An emphasis was made to allow for changes in the input criteria. It is easy to retrace steps back through the analysis to see what factors were included and what factors need to be changed (if necessary). Finally, it allows NAVFAC to be in a position to state clearly the procedures, factors, and rationale that were used for making the final decision.

Table 1. Advantages and Disadvantages of Existing RRR Techniques

RRR Repair Technique	Advantages	Disadvantages
FRP Mat	Economical Long shelf life	Mat size not easily changed
FRP Panel	Low weight and cube storage Air transportable Long shelf life Can be bolted together to form different dimensions	Expensive Labor intensive
FRP Foldable Mat	Economical Air transportable	Hinges are unproven Mat size not easily changed
Magnesium Phosphate	Long shelf life Semipermanent repair Flush repair	Expensive Setting time difficult to control Poor results in extreme cold Special equipment needed
Polyurethane Cap	Almost totally mechanized Semipermanent repair Flush repair	Expensive Complex system Special equipment needed Toxic materials Difficult to store Short shelf life
Concrete Slabs	Simple Good peacetime applications Long shelf life Economical	Slow repair time Labor intensive Equipment intensive Special equipment needed Manual skill required
Asphalt Blocks	Simple Good peacetime applications Long shelf life Economical Semipermanent repair Flush repair	Special equipment needed Labor intensive
Crushed Rock	Simple Economical	Not effective in heavy rain Need high compaction effort
AM-2 Matting	Long shelf life Readily available in current inventory Can be assembled to form different dimensions Air transportable Low weight and cube storage	Labor intensive Expensive Possible problem with mat thickness (1-1/2 inch)

Table 2. Selected Criteria and Weighted Values

Criteria	Value	Percent
Deployment Time	100	16.4
Structural Strength (sorties supported prior to first repair)	60	9.8
Complexity (level of skill required)	60	9.8
Labor Intensiveness	50	8.2
Equipment Intensiveness	50	8.2
Maintenance Difficulty	50	8.2
Dependency	45	7.4
Operational (under wide temperature range)	40	6.6
Operational (under wide aircraft range)	40	6.6
Shelf Life	30	4.9
Utility (can material and equipment be used for other missions, i.e., taxiways, ALRS)	20	3.3
Need for Dedicated Equipment	20	3.3
Material Cost	20	3.3
Storage	15	2.5
Peacetime Usage	10	1.6
		100

Table 3. Utility Values for State of Nature 1 (SN1)

Criteria	Weighting Factor	Candidate								
		AM-2	Polyurethane Cap	Magnesium Phosphate	FRP (Mat)	FRP (Panel)	FRP (Folded)	Asphalt Blocks	Concrete Slabs	Crushed Rocks
Initial Repair Time	100.00	8.80	9.60	9.60	8.80	8.80	8.80	8.80	7.00	9.10
Structural Strength	60.00	9.20	9.80	9.80	8.80	8.80	8.40	9.60	9.60	7.40
Complexity	60.00	9.80	4.30	7.50	10.00	9.80	9.80	9.80	7.50	10.00
Labor Intensity	50.00	3.00	8.00	7.00	6.00	4.00	6.00	7.00	2.00	9.00
Equipment Intensity	50.00	9.80	8.20	8.20	9.80	9.80	9.60	9.00	8.20	9.40
Maintenance Difficulty	50.00	8.70	10.00	10.00	8.70	8.70	8.70	10.00	10.00	10.00
Dependability	45.00	9.00	8.00	8.00	8.00	8.00	8.00	7.00	5.00	8.00
Operational Aircraft	40.00	8.80	10.00	10.00	10.00	10.00	10.00	10.00	10.00	8.80
Operational Temperature	40.00	10.00	10.00	9.50	10.00	10.00	10.00	9.90	10.00	10.00
Shelf Life	30.00	10.00	7.00	9.20	10.00	10.00	9.20	10.00	10.00	8.50
Utility	20.00	9.00	8.00	8.00	6.00	7.00	6.00	9.00	6.00	10.00
Material Cost	20.00	0.00	0.00	0.00	10.00	8.70	9.70	10.00	10.00	10.00
Need for Dedicated Equipment	20.00	10.00	6.00	9.00	10.00	10.00	10.00	9.00	9.00	10.00
Storage	15.00	8.00	3.00	5.00	6.00	8.00	7.00	9.00	9.00	8.00
Peacetime Usage	10.00	8.00	0.00	4.00	1.00	1.00	0.00	8.00	9.00	5.00

Table 4. Utility Values for State of Nature 2 (SN2)

Criteria	Weighting Factor	Candidate								
		AM-2	Polyurethane Cap	Magnesium Phosphate	FRP (Mat)	FRP (Panel)	FRP (Folded)	Asphalt Blocks	Concrete Slabs	Crushed Rocks
Initial Repair Time	100.00	7.80	9.20	7.80	7.80	7.80	7.80	7.80	6.00	0.80
Structural Strength	60.00	8.80	9.80	9.80	8.80	8.40	8.40	9.60	9.60	0.80
Complexity	60.00	9.80	4.30	7.50	10.00	9.80	9.80	9.80	7.50	10.00
Labor Intensity	50.00	2.00	8.00	7.00	5.00	3.00	5.00	6.00	1.00	8.00
Equipment Intensity	50.00	9.80	8.20	8.20	9.80	9.80	9.60	9.00	8.20	9.40
Maintenance Difficulty	50.00	7.70	10.00	10.00	7.70	7.70	7.70	10.00	10.00	0.00
Dependability	45.00	9.00	8.00	8.00	8.00	8.00	8.00	7.00	5.00	8.00
Operational Aircraft	40.00	8.80	10.00	10.00	10.00	10.00	10.00	10.00	10.00	8.80
Operational Temperature	40.00	10.00	10.00	9.50	10.00	10.00	10.00	9.90	10.00	5.20
Shelf Life	30.00	10.00	7.00	9.20	10.00	10.00	9.20	10.00	10.00	8.50
Utility	20.00	9.00	8.00	8.00	6.00	7.00	6.00	9.00	6.00	5.00
Material Cost	20.00	0.00	0.00	0.00	10.00	8.70	9.70	10.00	10.00	10.00
Need for Dedicated Equipment	20.00	10.00	6.00	6.00	10.00	10.00	10.00	6.00	9.00	9.00
Storage	15.00	8.00	3.00	5.00	6.00	8.00	7.00	9.00	9.00	8.00
Peacetime Usage	10.00	8.00	0.00	4.00	1.00	1.00	0.00	8.00	9.00	5.00

Table 5. Utility Values for State of Nature 3 (SN3)

Criteria	Weighting Factor	Candidate								
		AM-2	Polyurethane Cap	Magnesium Phosphate	FRP (Mat)	FRP (Panel)	FRP (Folded)	Asphalt Blocks	Concrete Slabs	Crushed Rocks
Initial Repair Time	100.00	7.90	9.10	9.30	7.90	7.90	7.90	7.90	5.00	8.70
Structural Strength	60.00	9.20	9.80	9.80	8.80	8.80	8.40	9.60	9.60	7.40
Complexity	60.00	9.80	4.30	7.50	10.00	9.80	9.80	9.80	7.50	10.00
Labor Intensity	50.00	1.00	8.00	7.00	5.00	2.00	5.00	6.00	0.50	8.50
Equipment Intensity	50.00	9.80	8.20	8.20	9.80	9.80	9.60	9.00	8.20	9.40
Maintenance Difficulty	50.00	8.70	10.00	10.00	8.70	8.70	8.70	10.00	10.00	10.00
Dependability	45.00	9.00	8.00	8.00	8.00	8.00	8.00	7.00	5.00	8.00
Operational Aircraft	40.00	8.80	10.00	10.00	10.00	10.00	10.00	10.00	10.00	8.80
Operational Temperature	40.00	10.00	10.00	9.50	10.00	10.00	10.00	9.90	10.00	10.00
Shelf Life	30.00	10.00	7.00	9.20	10.00	10.00	9.20	10.00	10.00	8.50
Utility	20.00	9.00	8.00	8.00	6.00	7.00	6.00	9.00	6.00	10.00
Material Cost	20.00	0.00	0.00	0.00	10.00	8.70	9.70	10.00	10.00	10.00
Need for Dedicated Equipment	20.00	10.00	6.00	9.00	10.00	10.00	10.00	9.00	9.00	10.00
Storage	15.00	8.00	3.00	5.00	6.00	8.00	7.00	9.00	9.00	8.00
Peacetime Usage	10.00	8.00	0.00	4.00	1.00	1.00	0.00	8.00	9.00	5.00

Table 6. Decision Matrix for State of Nature 1 (SN1) with Weighted Values

Criteria	Weighting Factor	Percentage	Candidate								
			AM-2	Polyurethane Cap	Magnesium Phosphate	FRP (Mat)	FRP (Panel)	FRP (Folded)	Asphalt Blocks	Concrete Slabs	Crushed Rocks
Initial Repair Time	100.00	16.4	880.00	960.00	960.00	880.00	880.00	880.00	880.00	700.00	910.00
Structural Strength	60.00	9.8	552.00	588.00	588.00	528.00	528.00	504.00	576.00	576.00	444.00
Complexity	60.00	9.8	588.00	258.00	450.00	600.00	588.00	588.00	588.00	450.00	600.00
Labor Intensity	50.00	8.2	150.00	400.00	350.00	300.00	200.00	300.00	350.00	100.00	450.00
Equipment Intensity	50.00	8.2	490.00	410.00	410.00	490.00	490.00	480.00	450.00	410.00	470.00
Maintenance Difficulty	50.00	8.2	435.00	500.00	500.00	435.00	435.00	435.00	500.00	500.00	500.00
Dependability	45.00	7.4	405.00	360.00	360.00	360.00	360.00	360.00	315.00	225.00	360.00
Operational Aircraft	40.00	6.6	352.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	352.00
Operational Temperature	40.00	6.6	400.00	400.00	380.00	400.00	400.00	400.00	396.00	400.00	400.00
Shelf Life	30.00	4.9	300.00	210.00	276.00	300.00	300.00	276.00	300.00	300.00	255.00
Utility	20.00	3.3	180.00	160.00	160.00	120.00	140.00	120.00	180.00	120.00	200.00
Material Cost	20.00	3.3	0.00	0.00	0.00	200.00	174.00	194.00	200.00	200.00	200.00
Need for Dedicated Equipment	20.00	3.3	200.00	120.00	180.00	200.00	200.00	200.00	180.00	180.00	200.00
Storage	15.00	2.5	120.00	45.00	75.00	90.00	120.00	105.00	135.00	135.00	120.00
Peacetime Usage	10.00	1.6	80.00	0.00	40.00	10.00	10.00	0.00	80.00	90.00	50.00
Total	610.00	100	5132.00	4811.00	5129.00	5313.00	5225.00	5242.00	5530.00	4786.00	5511.00

Table 7. Decision Matrix for State of Nature 2 (SN2) with Weighted Values

Criteria	Weighting Factor	Percentage	Candidate								
			AM-2	Polyurethane Cap	Magnesium Phosphate	FRP (Mat)	FRP (Panel)	FRP (Folded)	Asphalt Blocks	Concrete Slabs	Crushed Rocks
Initial Repair Time	100.00	16.4	780.00	920.00	780.00	780.00	780.00	780.00	780.00	600.00	80.00
Structural Strength	60.00	9.8	528.00	588.00	588.00	528.00	504.00	504.00	576.00	576.00	48.00
Complexity	60.00	9.8	588.00	258.00	450.00	600.00	588.00	588.00	588.00	450.00	600.00
Labor Intensity	50.00	8.2	100.00	400.00	350.00	250.00	150.00	250.00	300.00	50.00	400.00
Equipment Intensity	50.00	8.2	490.00	410.00	410.00	490.00	490.00	480.00	450.00	410.00	470.00
Maintenance Difficulty	50.00	8.2	385.00	500.00	500.00	385.00	385.00	385.00	500.00	500.00	0.00
Dependability	45.00	7.4	405.00	360.00	360.00	360.00	360.00	360.00	315.00	225.00	360.00
Operational Aircraft	40.00	6.6	352.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	352.00
Operational Temperature	40.00	6.6	400.00	400.00	380.00	400.00	400.00	400.00	396.00	400.00	208.00
Shelf Life	30.00	4.9	300.00	210.00	276.00	300.00	300.00	276.00	300.00	300.00	255.00
Utility	20.00	3.3	180.00	160.00	160.00	120.00	140.00	120.00	180.00	120.00	100.00
Material Cost	20.00	3.3	0.00	0.00	0.00	200.00	174.00	194.00	200.00	200.00	200.00
Need for Dedicated Equipment	20.00	3.3	200.00	120.00	120.00	200.00	200.00	200.00	120.00	180.00	180.00
Storage	15.00	2.5	120.00	45.00	75.00	90.00	120.00	105.00	135.00	135.00	120.00
Peacetime Usage	10.00	1.6	80.00	0.00	40.00	10.00	10.00	0.00	80.00	90.00	50.00
Total	610.00	100	4908.00	4771.00	4889.00	5113.00	5001.00	5042.00	5320.00	4636.00	3423.00

Table 8. Decision Matrix for State of Nature 3 (SN3) with Weighted Values

Criteria	Weighting Factor	Percentage	Candidate								
			AM-2	Polyurethane Cap	Magnesium Phosphate	FRP (Mat)	FRP (Panel)	FRP (Folded)	Asphalt Blocks	Concrete Slabs	Crushed Rocks
Initial Repair Time	100.00	16.4	790.00	910.00	930.00	790.00	790.00	790.00	790.00	500.00	870.00
Structural Strength	60.00	9.8	552.00	588.00	588.00	528.00	528.00	504.00	576.00	576.00	440.00
Complexity	60.00	9.8	588.00	258.00	450.00	600.00	588.00	588.00	588.00	450.00	600.00
Labor Intensity	50.00	8.2	50.00	400.00	350.00	250.00	100.00	250.00	300.00	25.00	425.00
Equipment Intensity	50.00	8.2	490.00	410.00	410.00	490.00	490.00	480.00	450.00	410.00	470.00
Maintenance Difficulty	50.00	8.2	435.00	500.00	500.00	435.00	435.00	435.00	500.00	500.00	500.00
Dependability	45.00	7.4	405.00	360.00	360.00	360.00	360.00	360.00	315.00	225.00	360.00
Operational Aircraft	40.00	6.6	352.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	352.00
Operational Temperature	40.00	6.6	400.00	400.00	380.00	400.00	400.00	400.00	396.00	400.00	400.00
Shelf Life	30.00	4.9	300.00	210.00	276.00	300.00	300.00	276.00	300.00	300.00	255.00
Utility	20.00	3.3	180.00	160.00	160.00	120.00	140.00	120.00	180.00	120.00	200.00
Material Cost	20.00	3.3	0.00	0.00	0.00	200.00	174.00	194.00	200.00	200.00	200.00
Need for Dedicated Equipment	20.00	3.3	200.00	120.00	180.00	200.00	200.00	200.00	180.00	180.00	200.00
Storage	15.00	2.5	120.00	45.00	75.00	90.00	120.00	105.00	135.00	135.00	200.00
Peacetime Usage	10.00	1.6	80.00	0.00	40.00	10.00	10.00	0.00	80.00	90.00	50.00
Total	610.00	100	4942.00	4761.00	5099.00	5173.00	5035.00	5102.00	5390.00	4511.00	5446.00

Table 9. Rank Total with SN1, SN2, and SN3 Ranks

Candidate	SN1 80%	SN1 Rank	SN2 15%	SN2 Rank	SN3 5%	SN3 Rank	Total 100%	Total Rank
Asphalt Blocks	4424.0	(1)	798.0	(1)	269.5	(2)	5491.5	(1)
FRP (Mat)	4250.4	(3)	766.9	(2)	258.7	(3)	5276.0	(2)
FRP (Folded)	4193.6	(4)	756.3	(3)	255.1	(4)	5205.0	(3)
Crushed Rocks	4408.8	(2)	513.4	(9)	272.3	(1)	5194.5	(4)
FRP (Panel)	4180.0	(5)	750.2	(4)	251.8	(6)	5182.0	(5)
Magnesium Phosphate	4103.2	(7)	733.4	(6)	255.0	(5)	5091.6	(6)
AM-2	4105.6	(6)	736.2	(5)	247.1	(7)	5088.9	(7)
Polyurethane Cap	3848.8	(8)	715.7	(7)	238.1	(8)	4802.6	(8)
Concrete Slabs	3828.8	(9)	695.4	(8)	225.6	(9)	4749.8	(9)

Final Score Calculation:

Asphalt Blocks = 5530 (0.80) + 5320 (0.15) + 5390 (0.05)

= 4424 + 798 + 269.5 = 5491.5

Table 10. Sensitivity Analysis

Alternative	SN1	SN2	SN3	SN2/SN1	SN3/SN
Asphalt Blocks	5530.00	5320.00	5390.00	0.96	0.97
FRP (Mat)	5313.00	5113.00	5173.00	0.96	0.97
FRP (Folded)	5242.00	5042.00	5102.00	0.96	0.97
Crushed Rocks	5511.00	3423.00	5446.00	0.62	0.99
FRP (Panel)	5225.00	5001.00	5035.00	0.96	0.96
Magnesium Phosphate	5129.00	4889.00	5099.00	0.95	0.99
AM-2	5132.00	4908.00	4942.00	0.96	0.96
Polyurethane Cap	4811.00	4771.00	4761.00	0.99	0.99
Concrete Slabs	4786.00	4636.00	4511.00	0.97	0.94

Table 11. Sensitivity Analysis for State of Nature 2

Criteria	Candidate								
	AM-2	Polyurethane Cap	Magnesium Phosphate	FRP (Mat)	FRP (Panel)	FRP (Folded)	Asphalt Blocks	Concrete Slabs	Crushed Rocks
Initial Repair Time	0.89	0.96	0.81	0.89	0.89	0.89	0.89	0.86	0.09
Structural Strength	0.96	1.00	1.00	1.00	0.95	1.00	1.00	1.00	0.11
Complexity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Labor Intensity	0.67	1.00	1.00	0.83	0.75	0.83	0.86	0.50	0.89
Equipment Intensity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Difficulty	0.89	1.00	1.00	0.89	0.89	0.89	1.00	1.00	0.00
Dependability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Operational Aircraft	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Operational Temperature	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.52
Shelf Life	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Utility	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50
Material Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Need for Dedicated Equipment	1.00	1.00	0.67	1.00	1.00	1.00	0.67	1.00	0.90
Storage	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Peacetime Usage	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	0.96	0.99	0.95	0.96	0.96	0.96	0.96	0.97	0.62

Table 12. Sensitivity Analysis for State of Nature 3.

Criteria	Candidate								
	AM-2	Polyurethane Cap	Magnesium Phosphate	FRP (Mat)	FRP (Panel)	FRP (Folded)	Asphalt Blocks	Concrete Slabs	Crushed Rocks
Initial Repair Time	0.90	0.95	0.97	0.90	0.90	0.90	0.90	0.71	0.96
Structural Strength	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Complexity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Labor Intensity	0.33	1.00	1.00	0.83	0.50	0.83	0.86	0.25	0.94
Equipment Intensity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Difficulty	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dependability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Operational Aircraft	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Operational Temperature	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Shelf Life	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Utility	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Material Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Need for Dedicated Equipment	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Storage	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Peacetime Usage	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	0.97	0.99	0.99	0.97	0.96	0.97	0.97	0.94	0.99

Figure 1. Rolling FRP laminate to expel trapped air

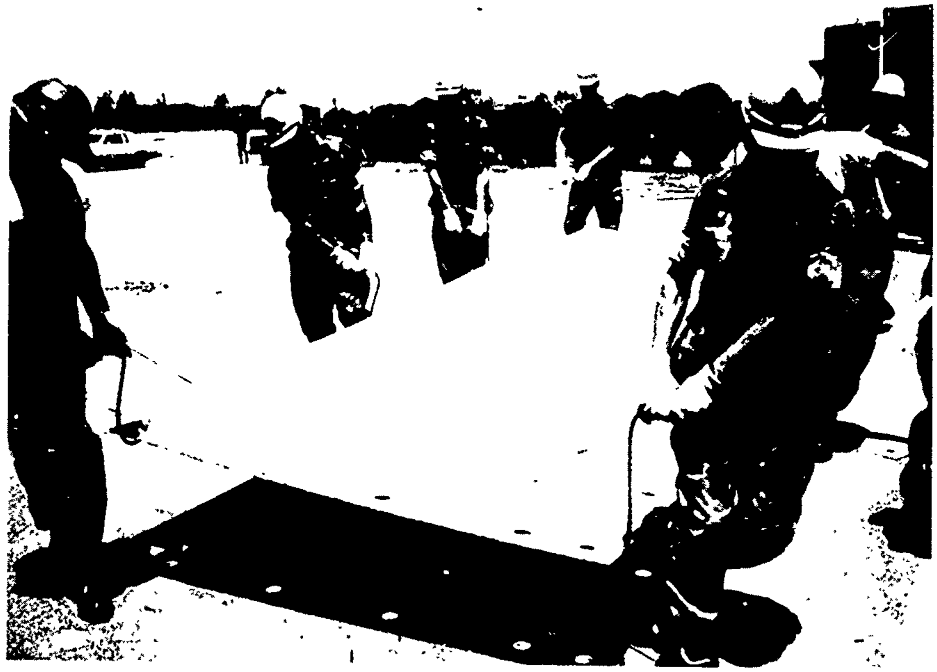


Figure 3. FRP panels ready for traffic.

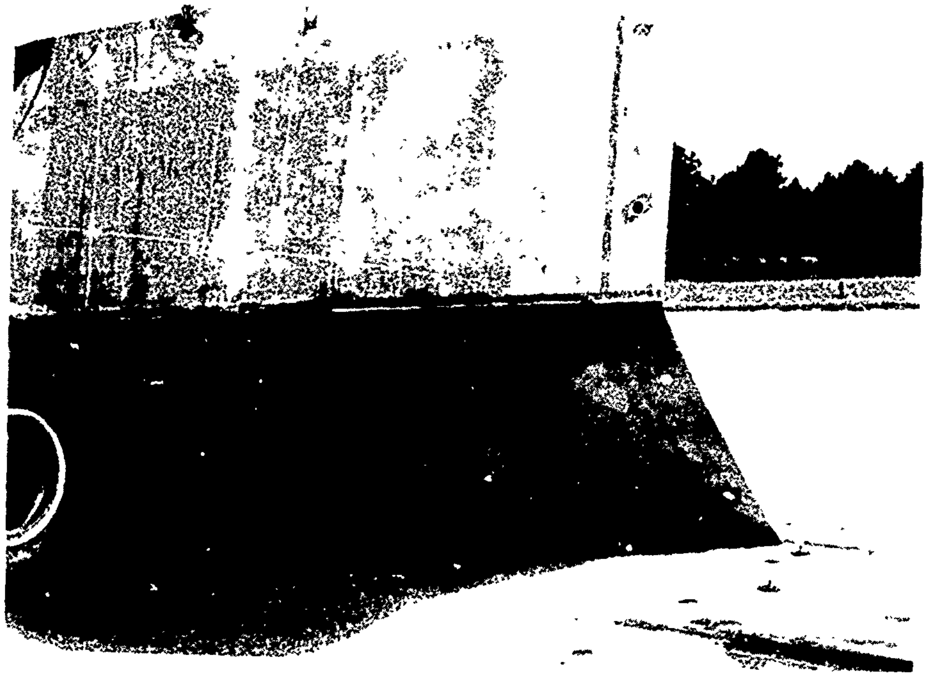


Figure 4. Placing foldable FRP mat.

Figure 5. Foldable FRP mat ready for traffic.

Figure 6. Placing concrete slabs inside crater.

Figure 7. Placing asphalt concrete blocks inside crater.

Figure 8. Compacting asphalt concrete blocks.

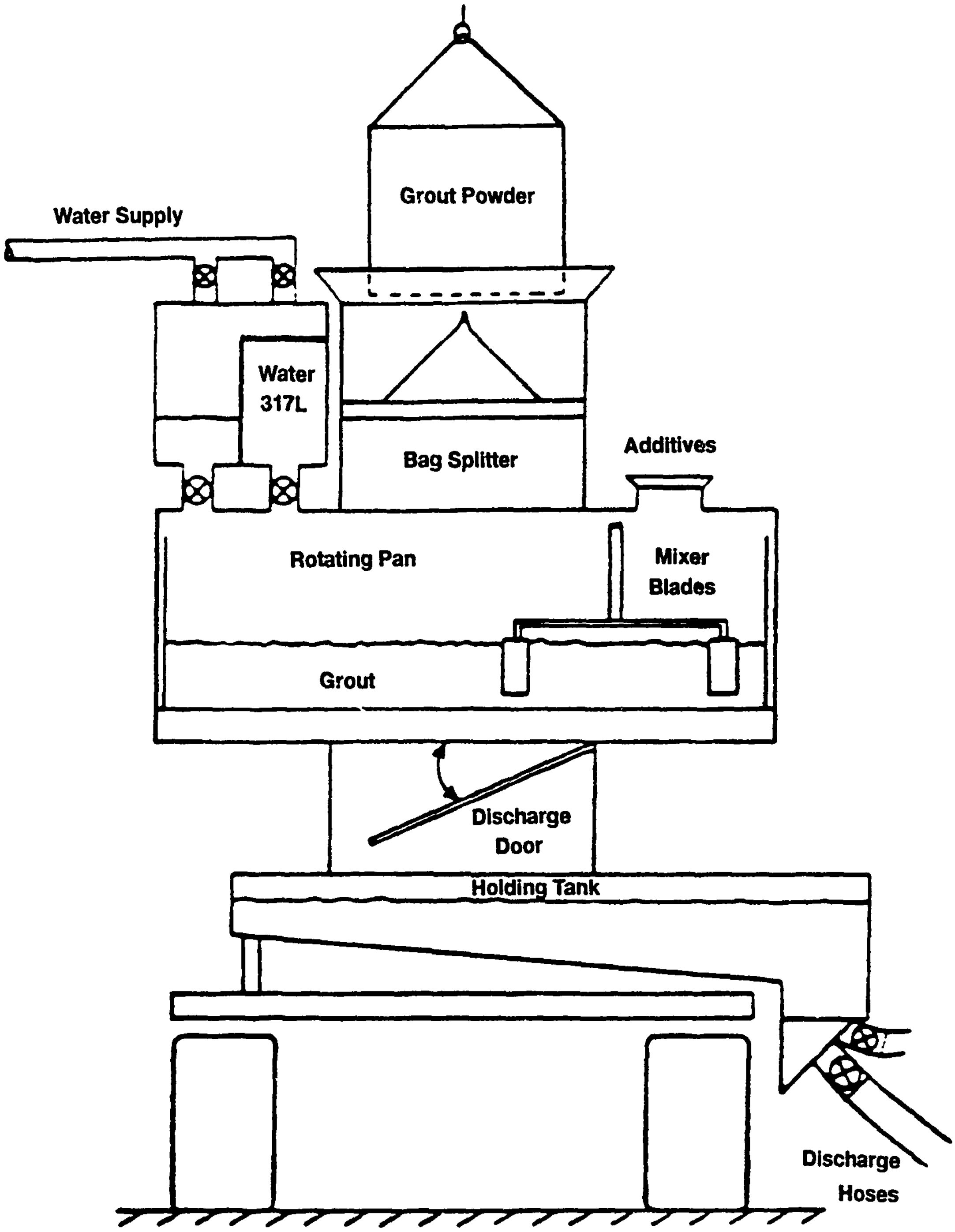


Figure 9. Schematic view of grout mixer system.

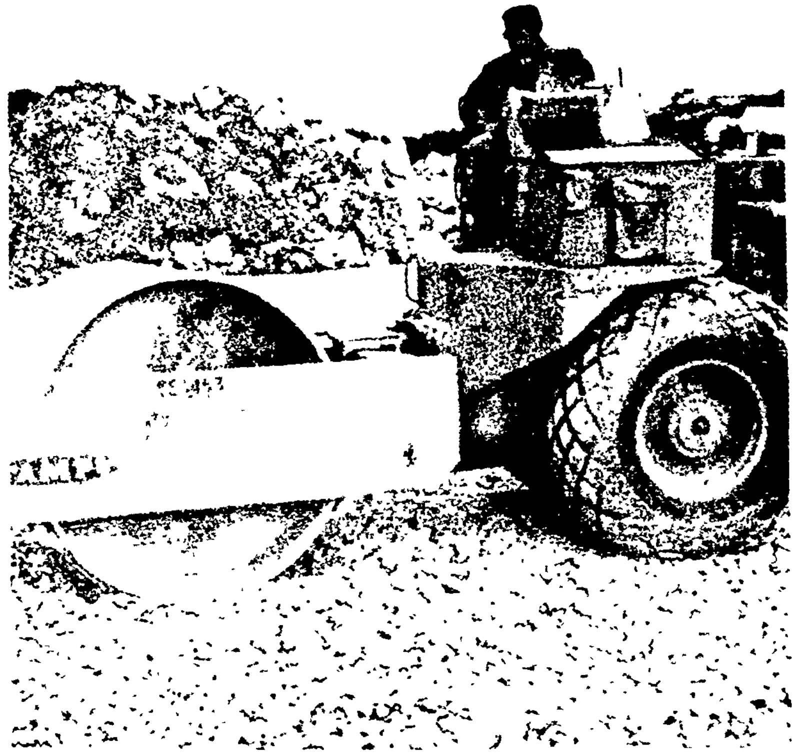


Figure 10. Rolling crushed stone with vibratory roller.

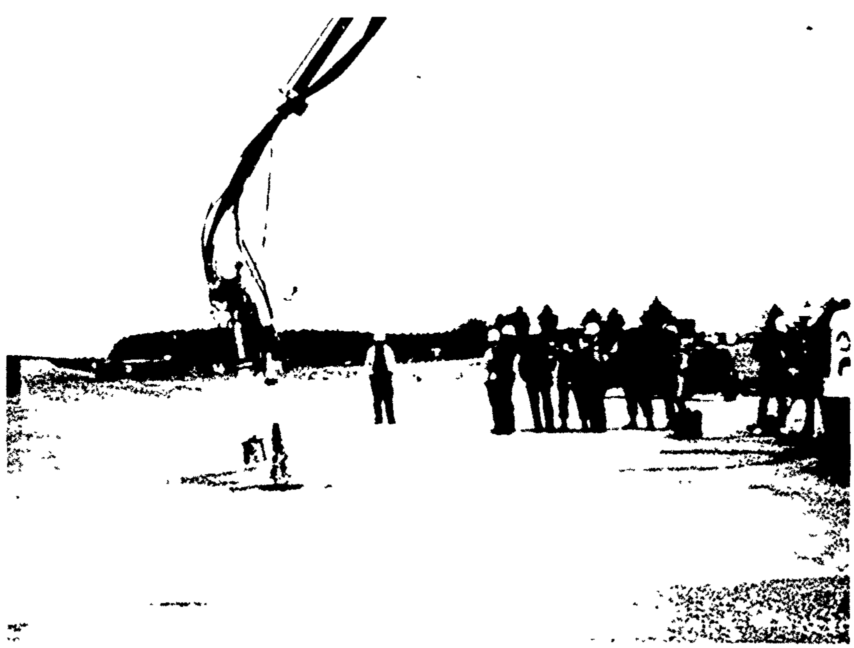


Figure 11. Spraying polyurethane resin inside crater.

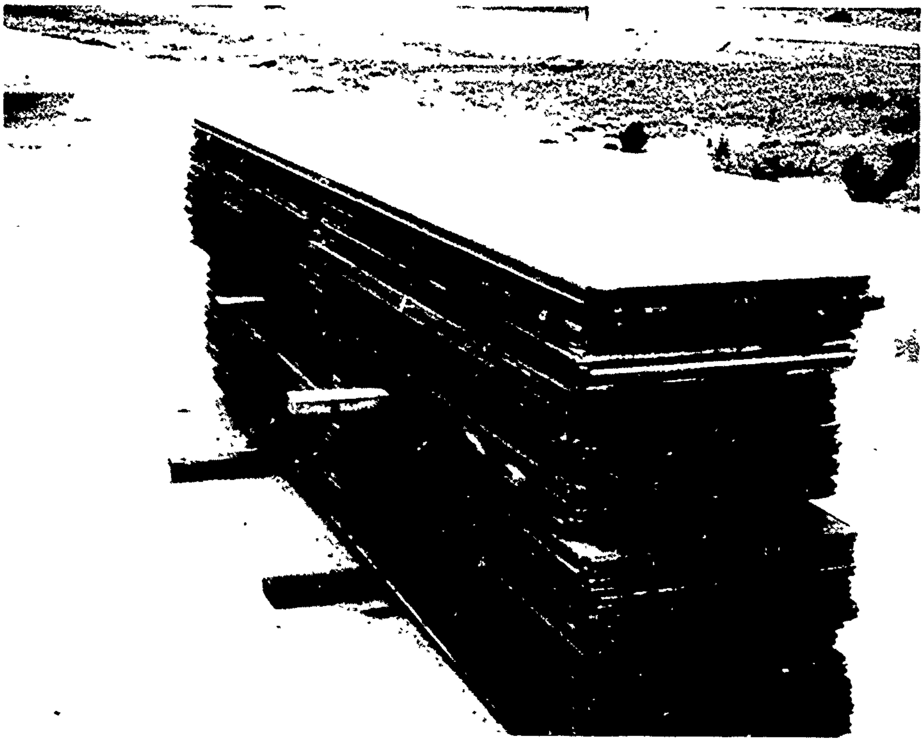


Figure 12. AM-2 matting.

Figure 13. INITIAL REPAIR TIME for SN1.
(hours)

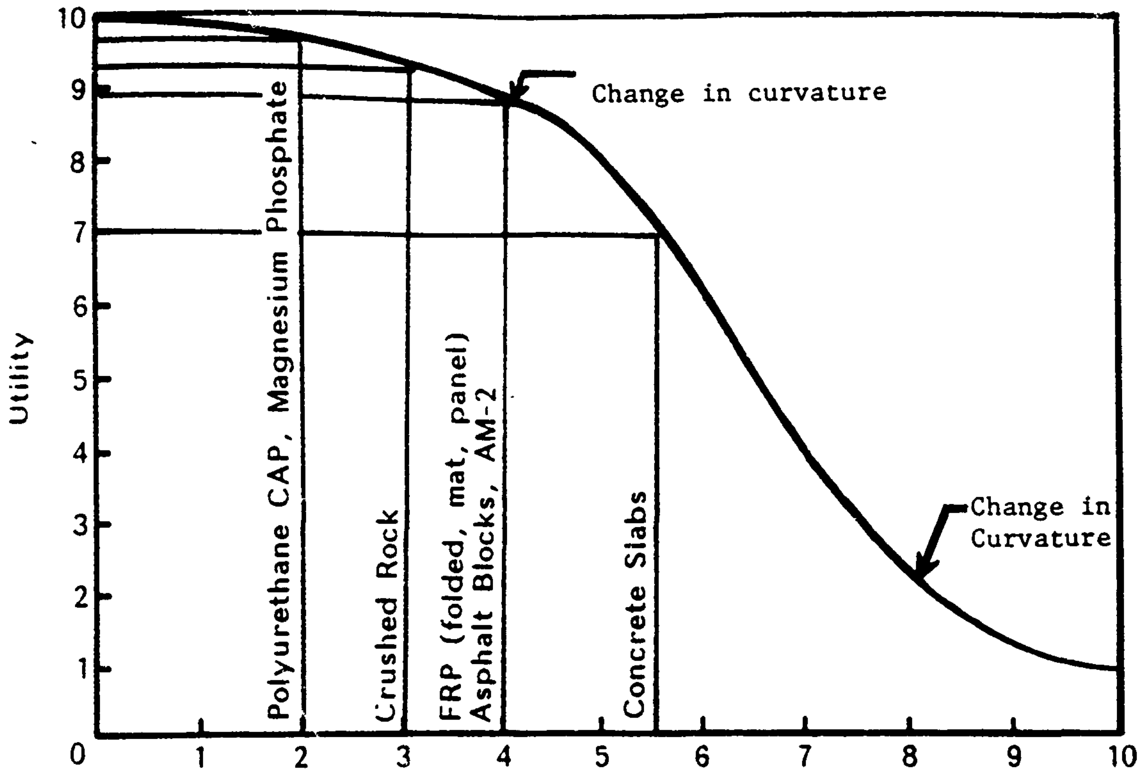


Figure 14. STRUCTURAL STRENGTH for SN1
(Traffic supported after initial and in between repairs).

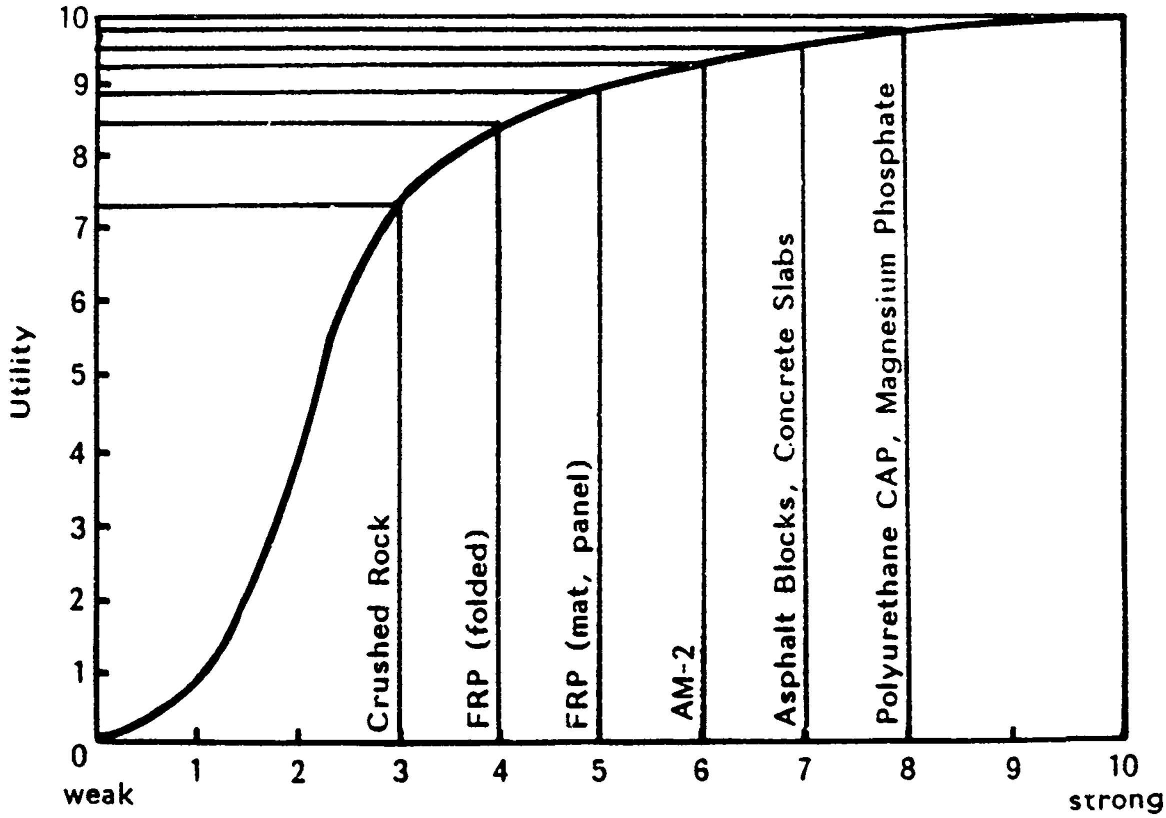


Figure 15. COMPLEXITY for SN1.

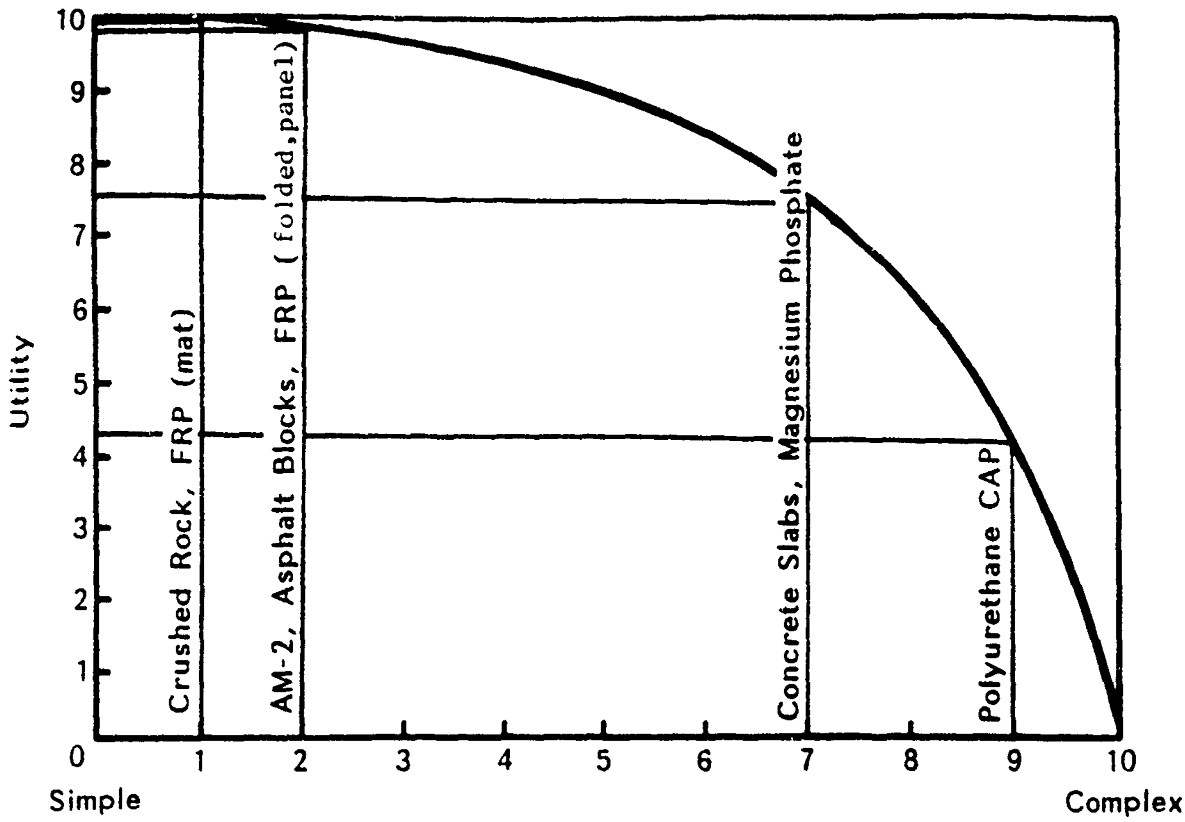


Figure 16. LABOR INTENSIVENESS for SN1.

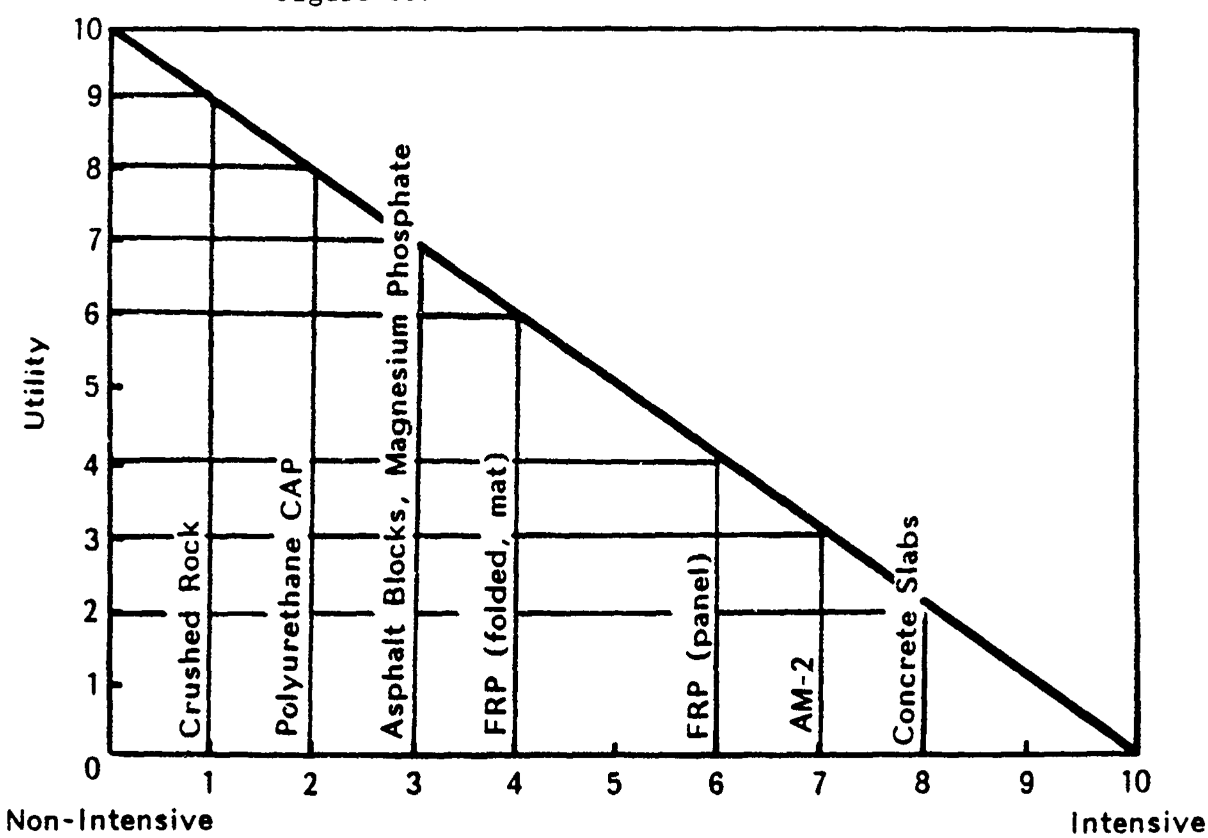


Figure 17. DEPENDENCY for SN1.
(On Prior Procedures)

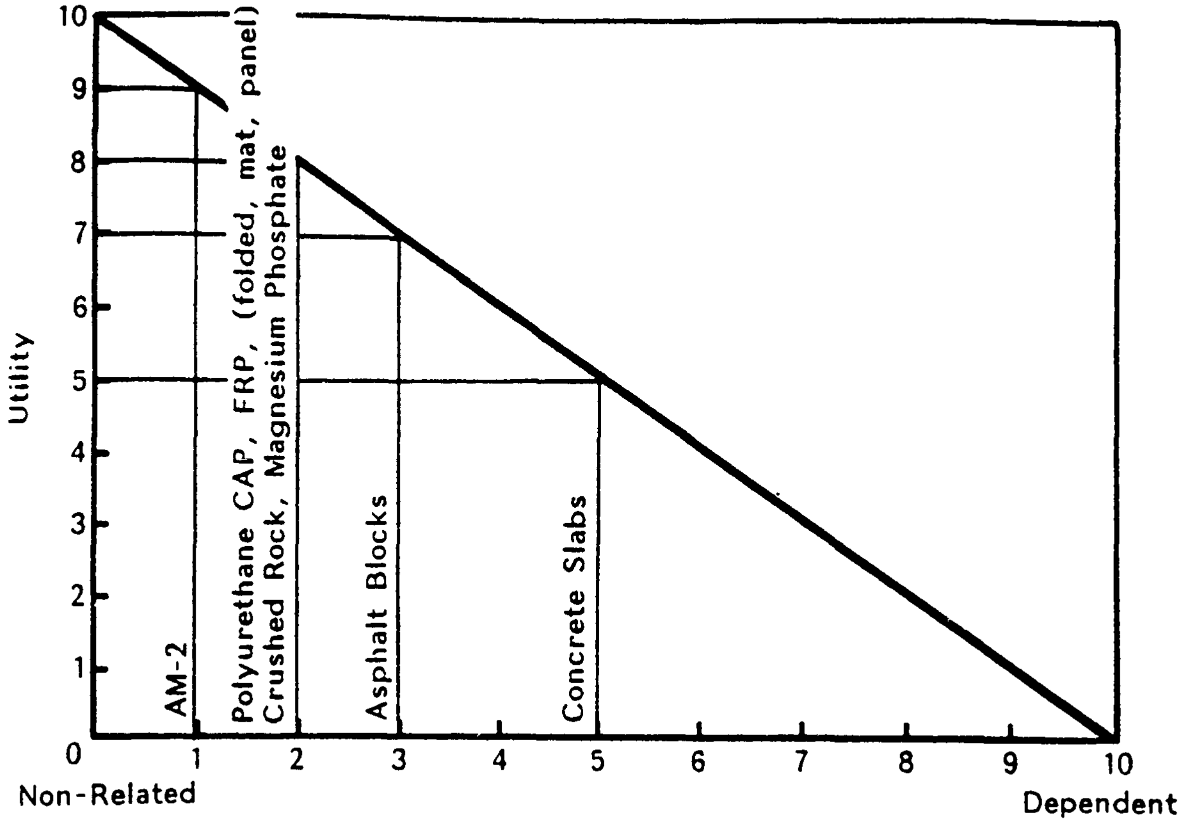


Figure 18. OPERATIONAL for SN1
(Under Wide Temperature Range).

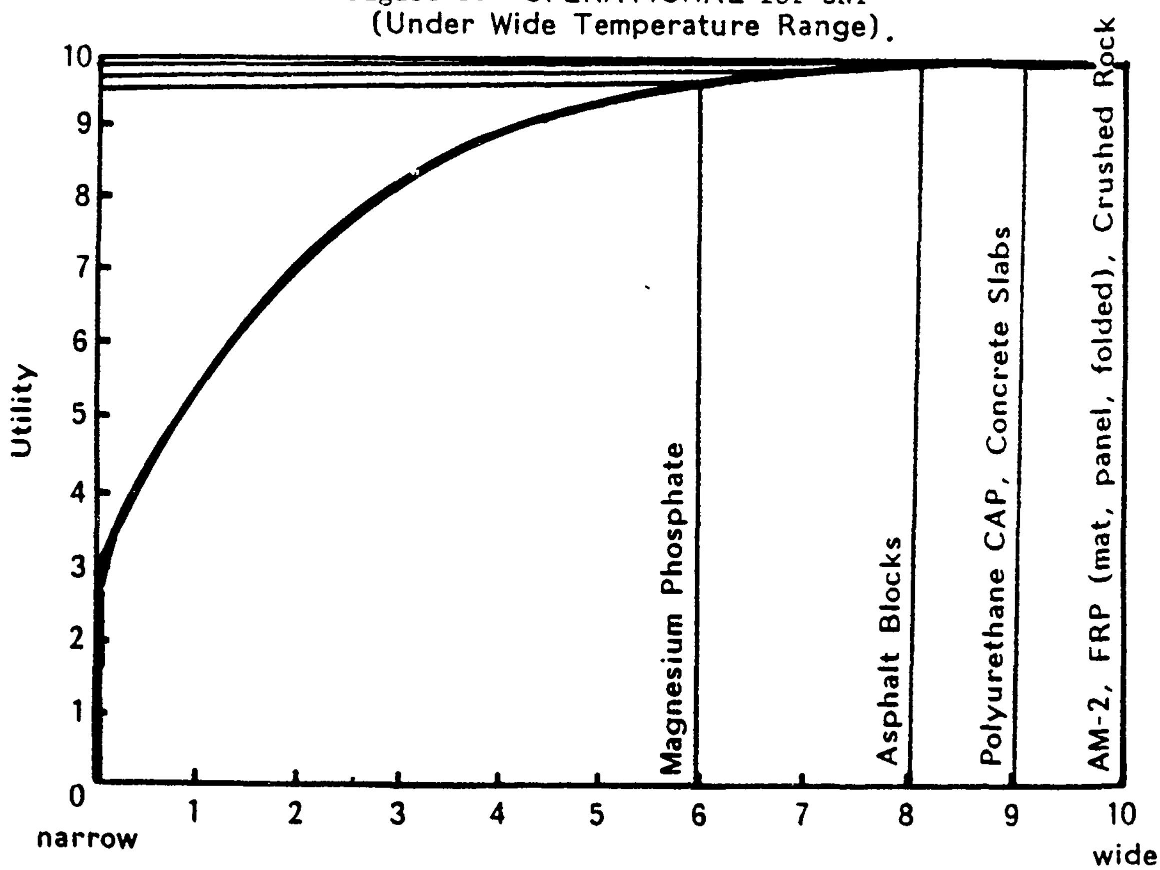


Figure 19. EQUIPMENT INTENSIVENESS for SN1.

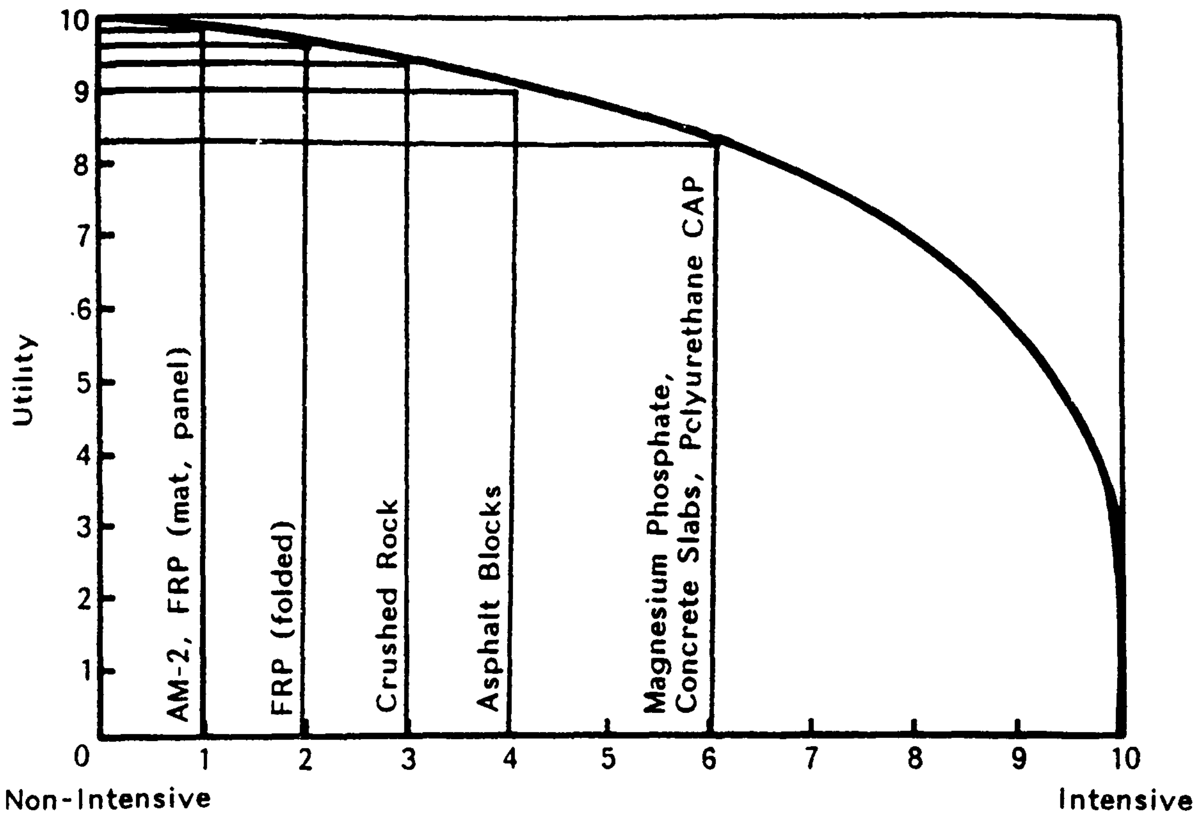


Figure 20. MAINTENANCE DIFFICULTY for SN1
(Need for maintenance and amount of difficulty).

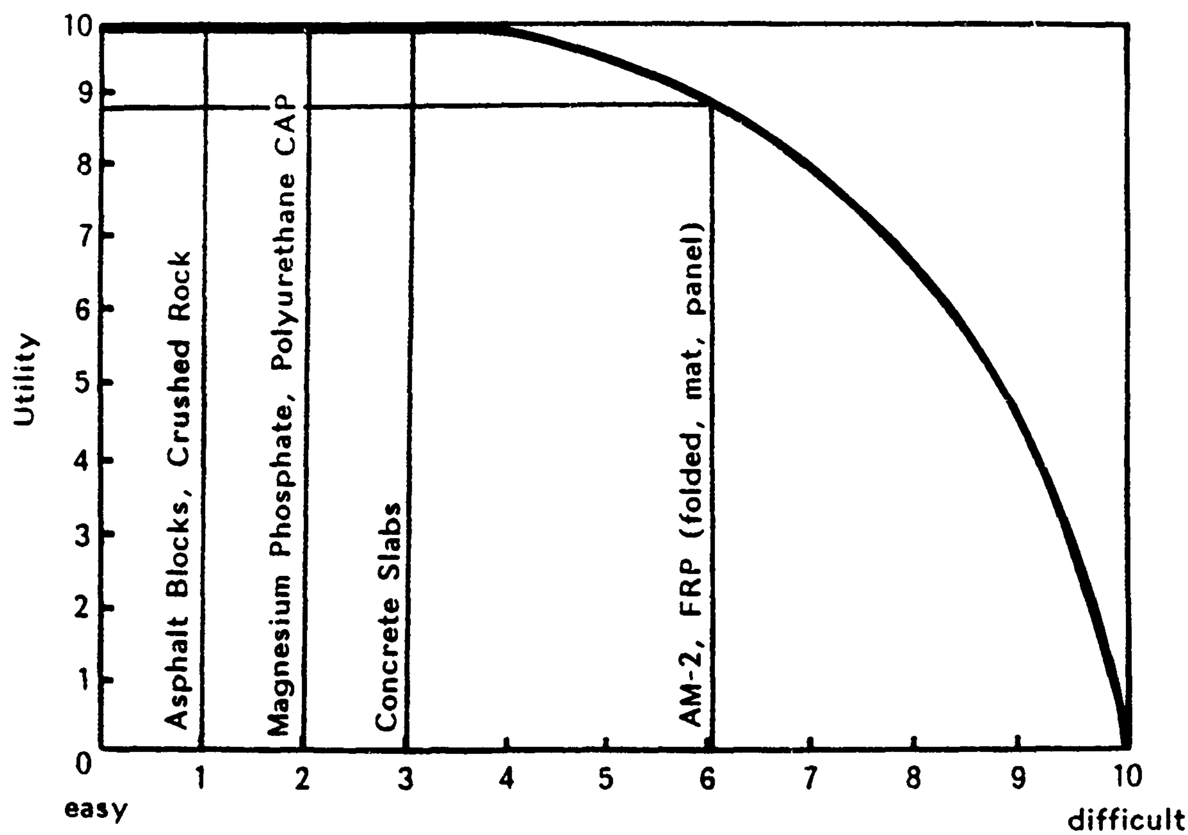


Figure 21. OPERATIONAL for SN1
(Types of Aircraft Supported).

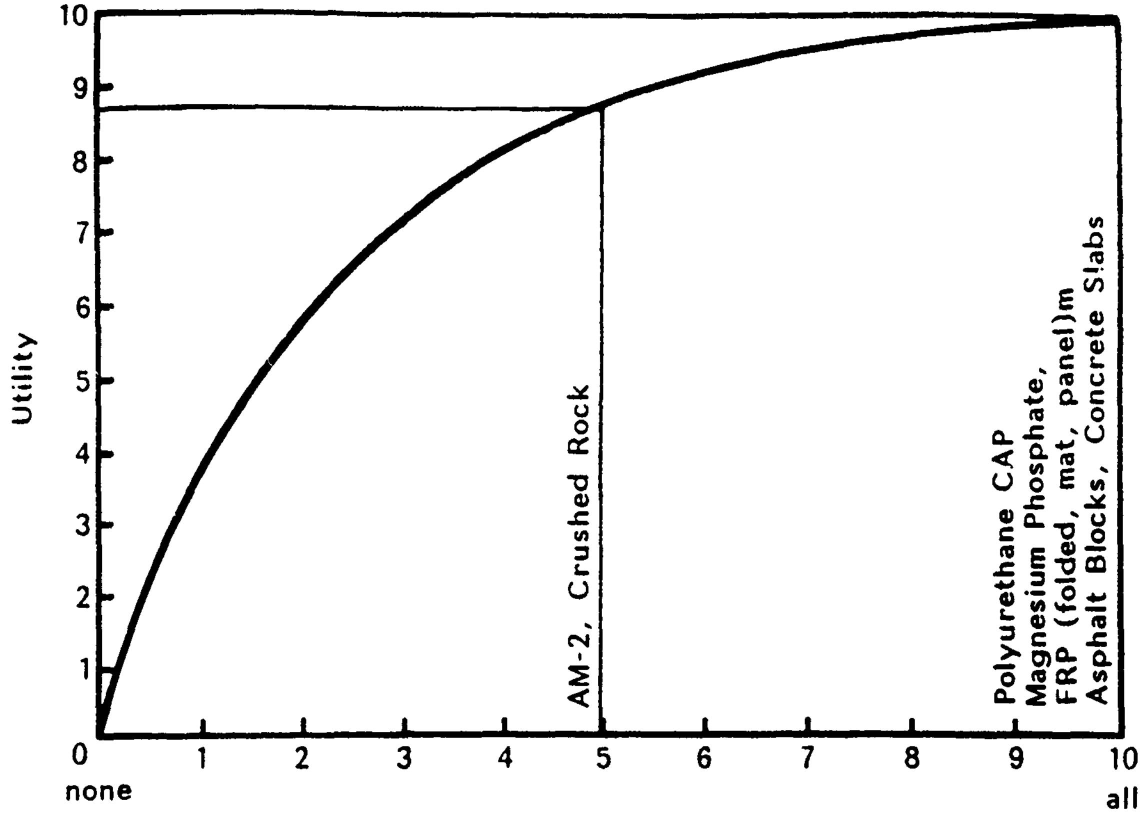


Figure 22. SHELF LIFE (YEARS) for SN1.

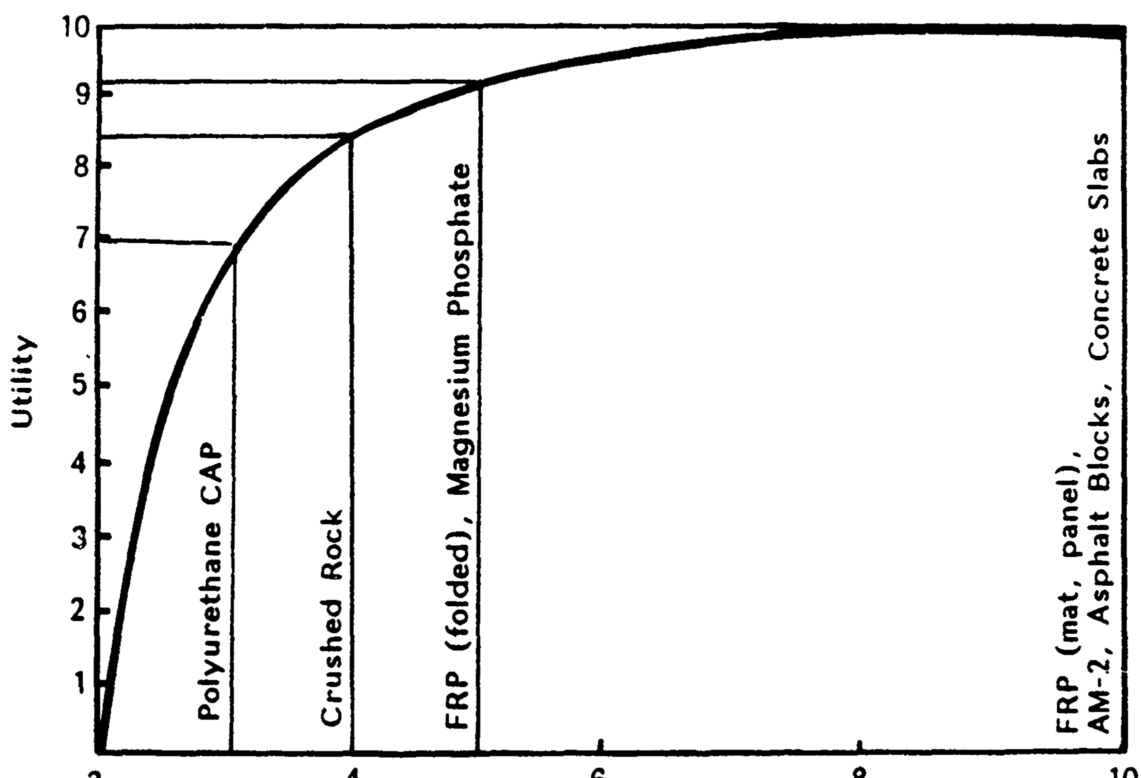


Figure 23. COST ($/sq. ft.) for SN1.

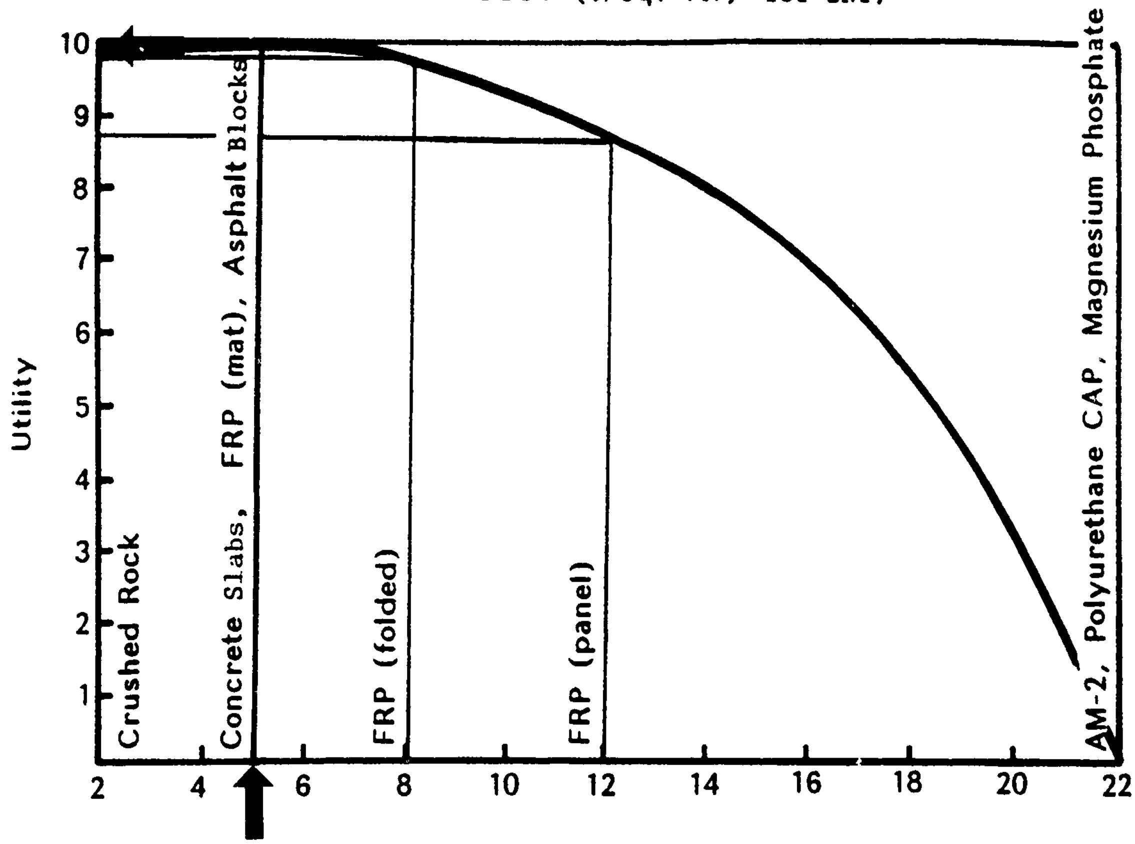


Figure 24. STORAGE for SN1.

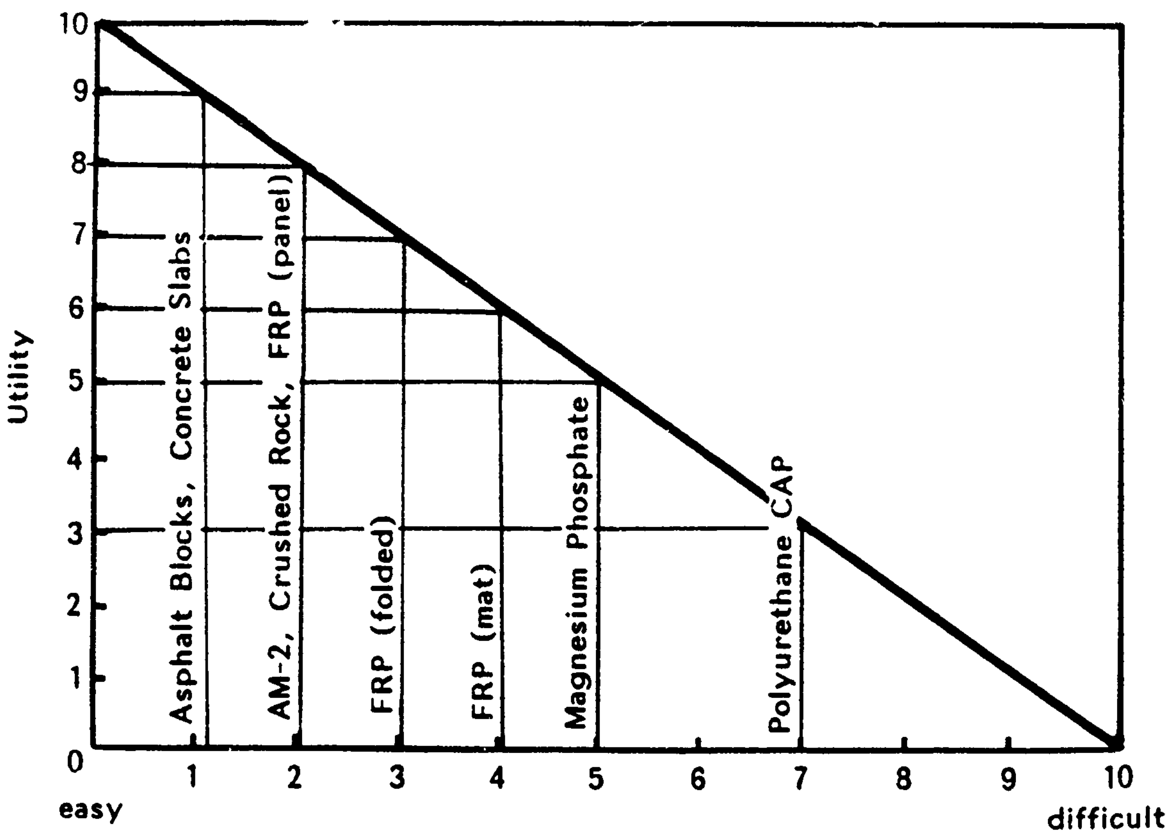


Figure 25. UTILITY for SN1.

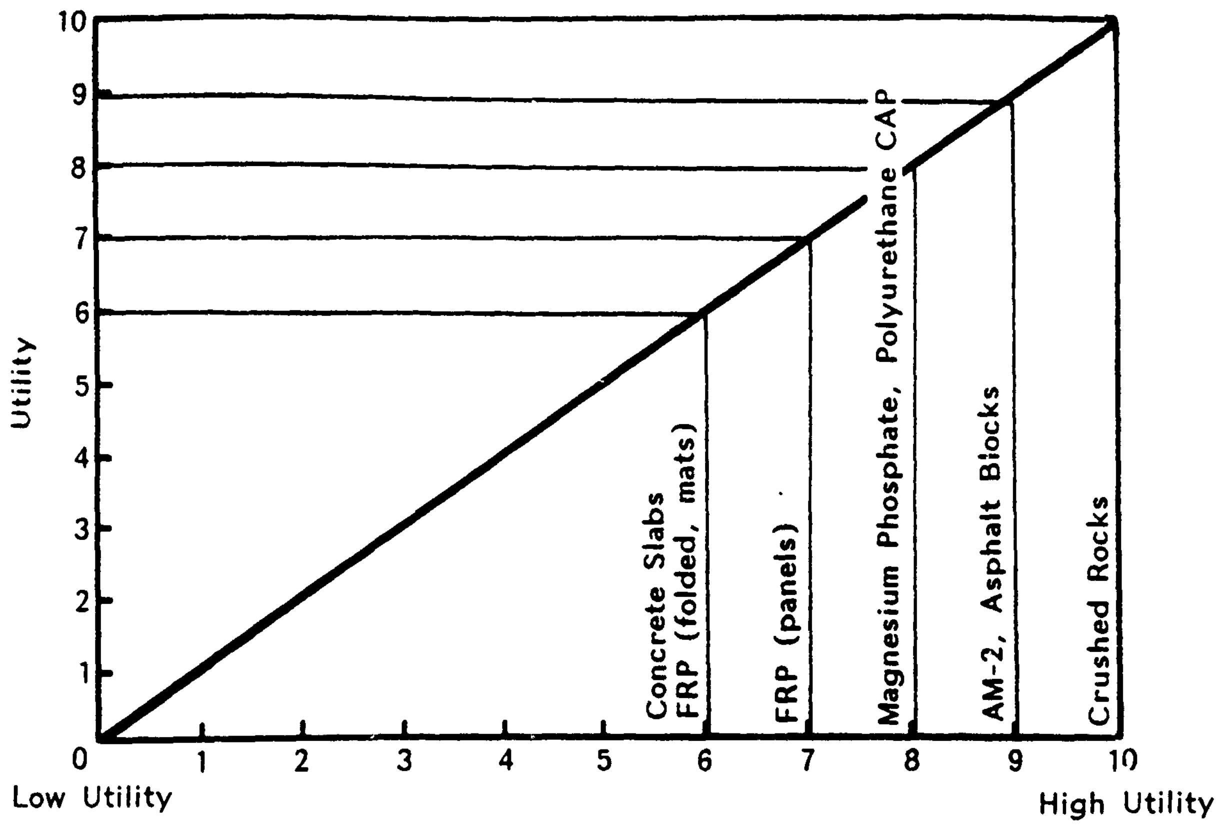


Figure 26. NEED FOR DEDICATED EQUIPMENT for SN1.
(Different Types of Dedicated Equip nt)

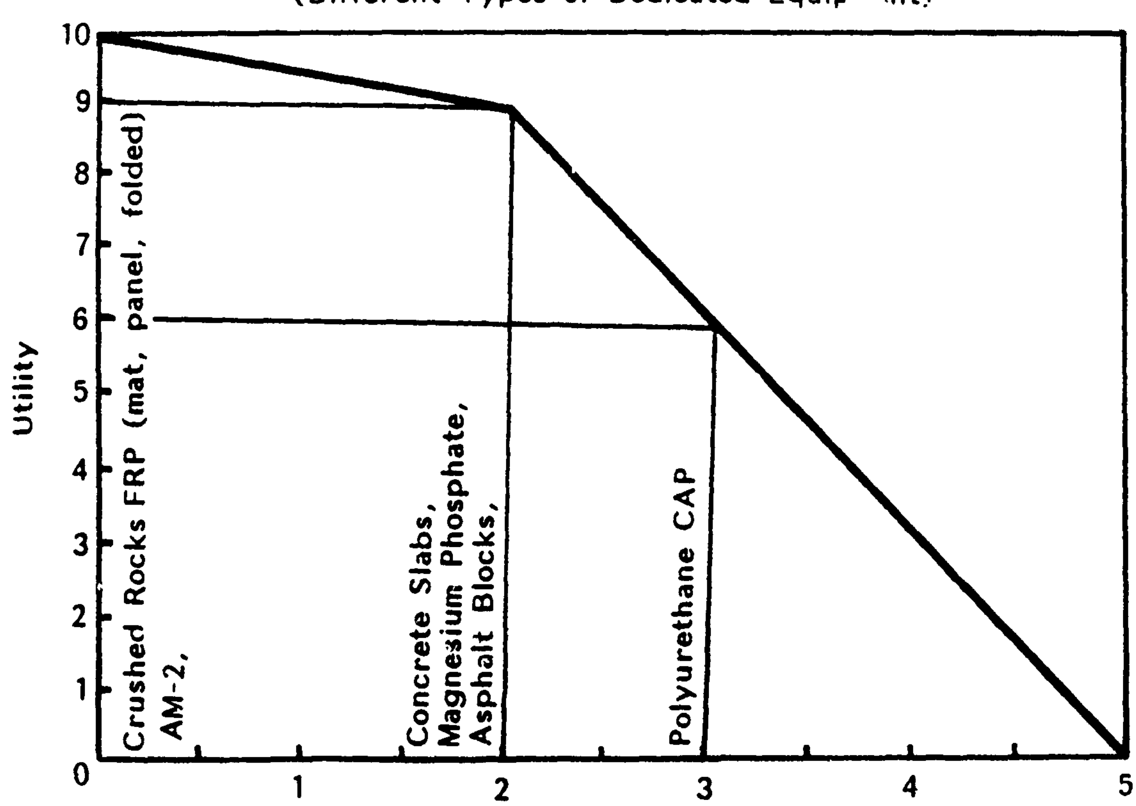


Figure 27. PEACE TIME USAGE for SN1.

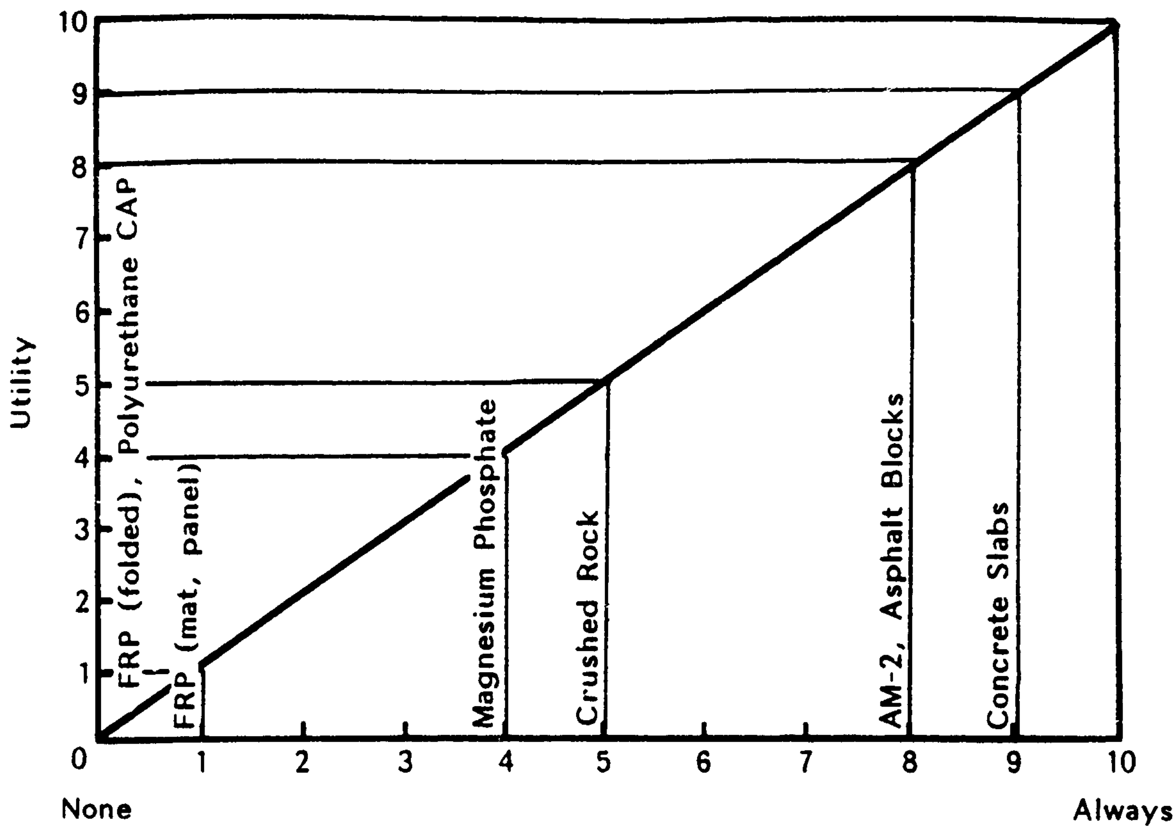


Figure 28. INITIAL REPAIR TIME for SN2.
(hours)

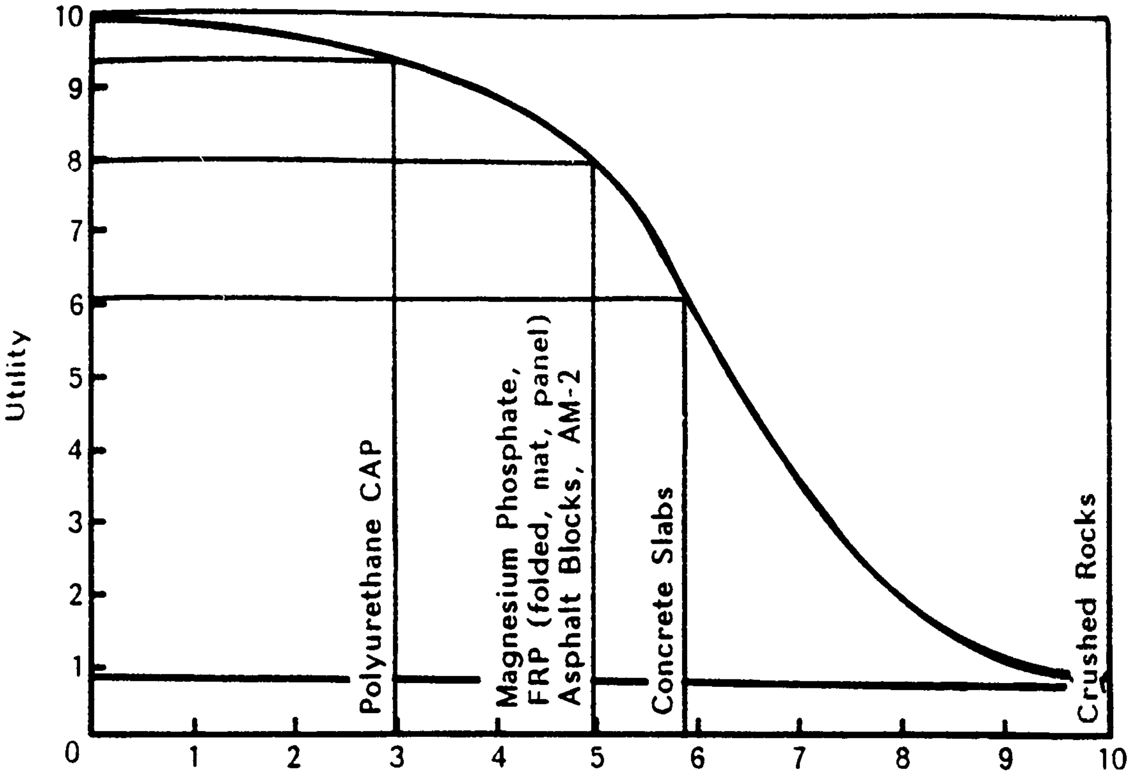


Figure 29. STRUCTURAL STRENGTH for SN2.
(Traffic supported after initial and in between repairs)

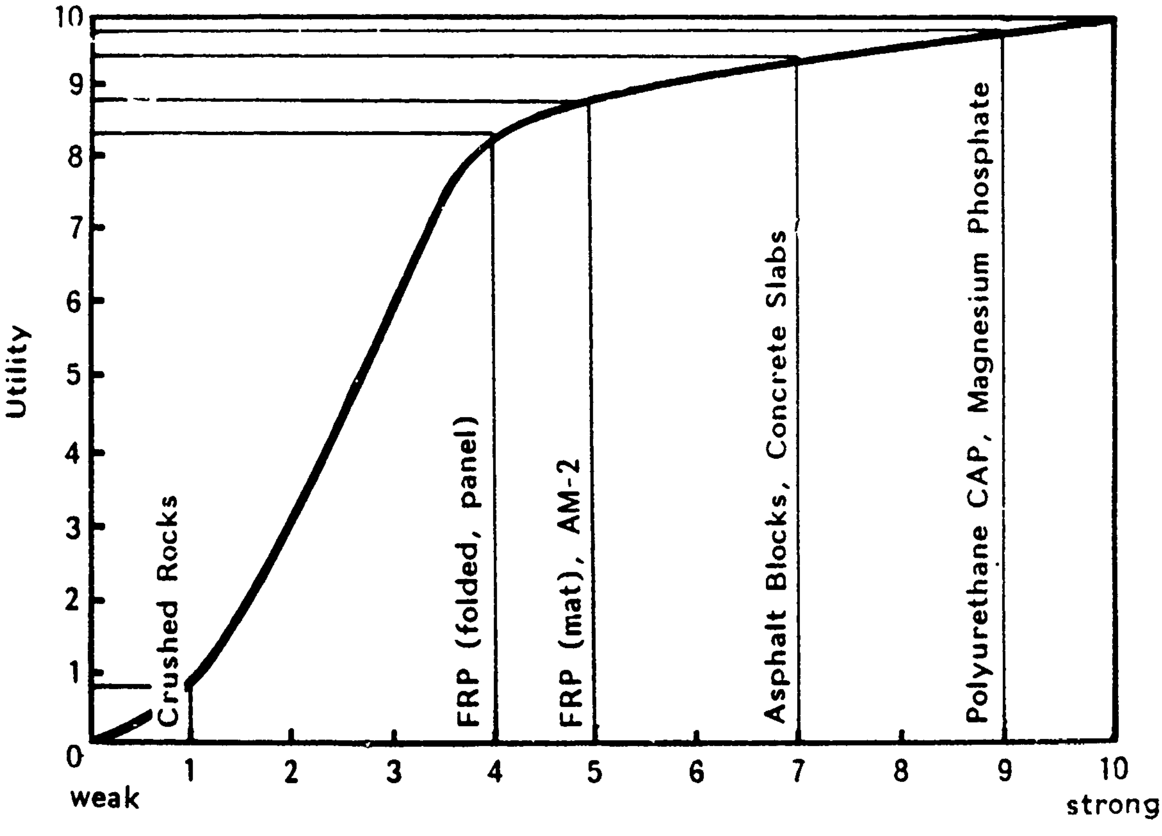


Figure 30. COMPLEXITY for SN2.

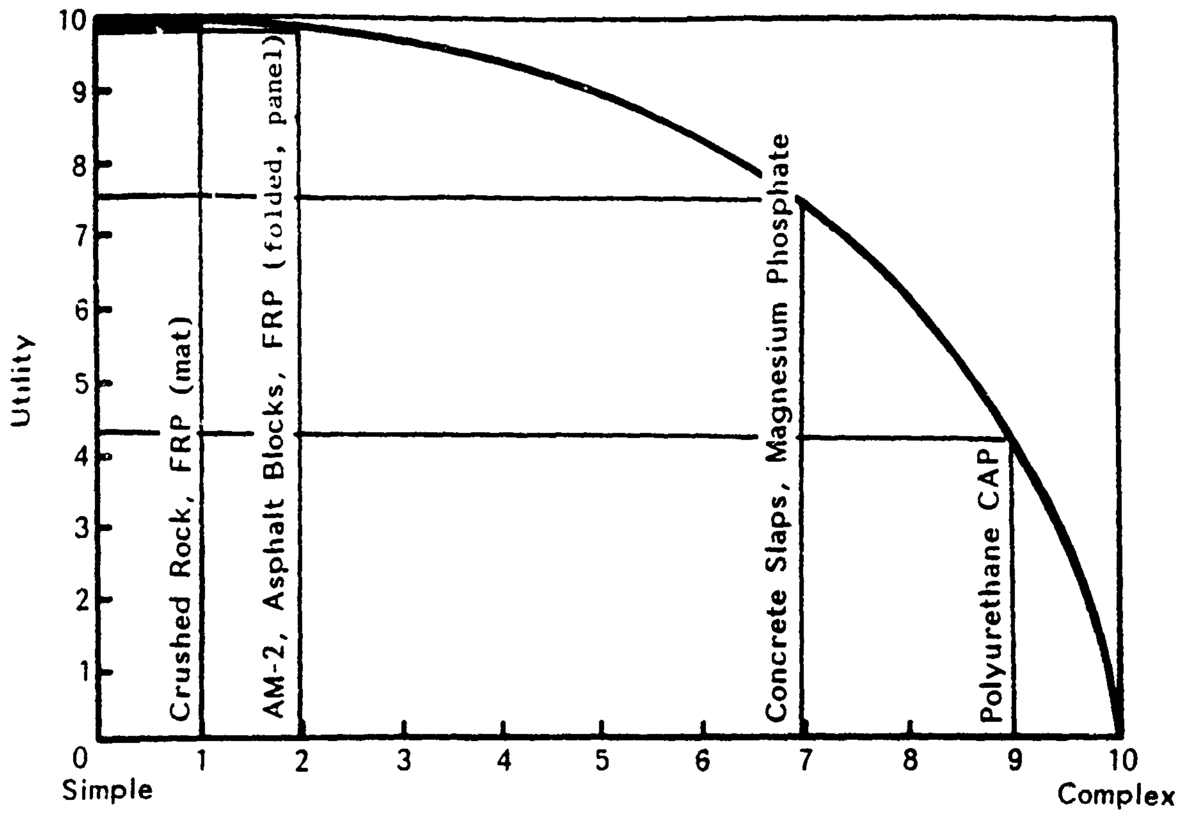


Figure 31. LABOR INTENSIVENESS for SN2.

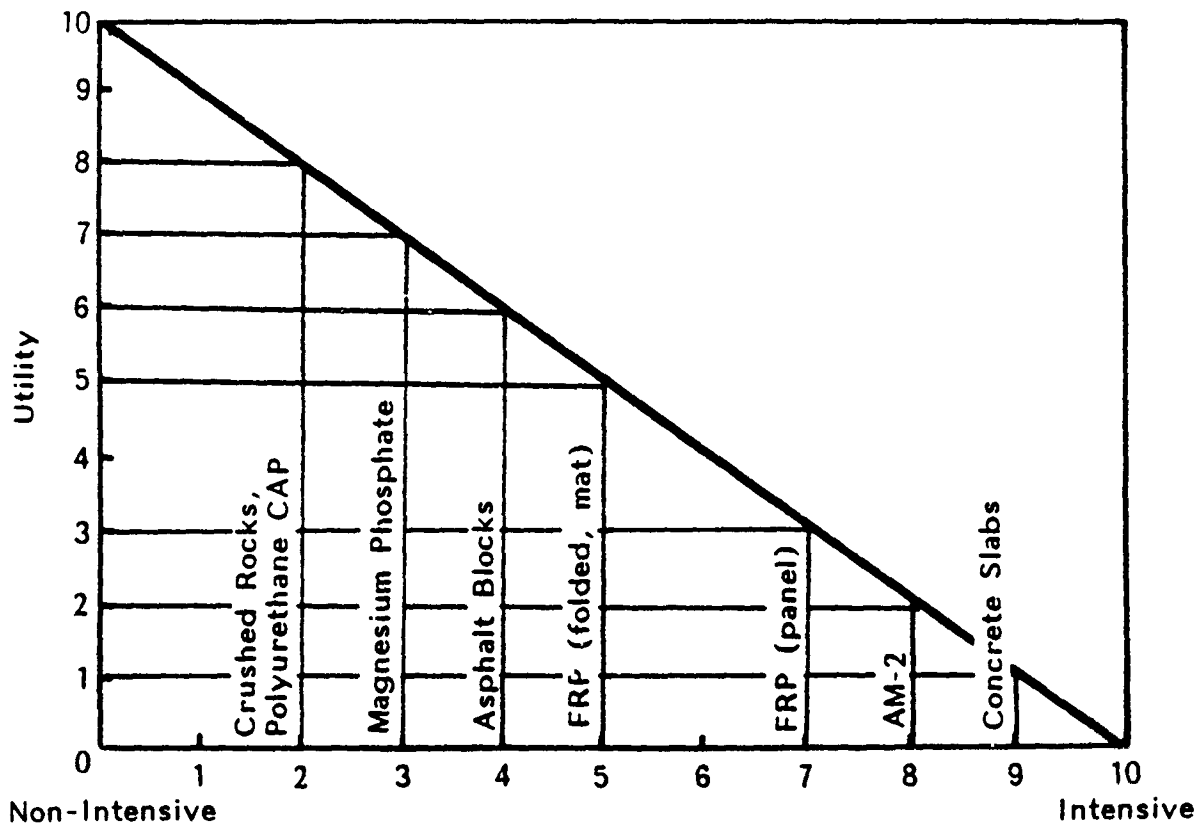


Figure 32. DEPENDENCY for SN2.
(On prior procedure)

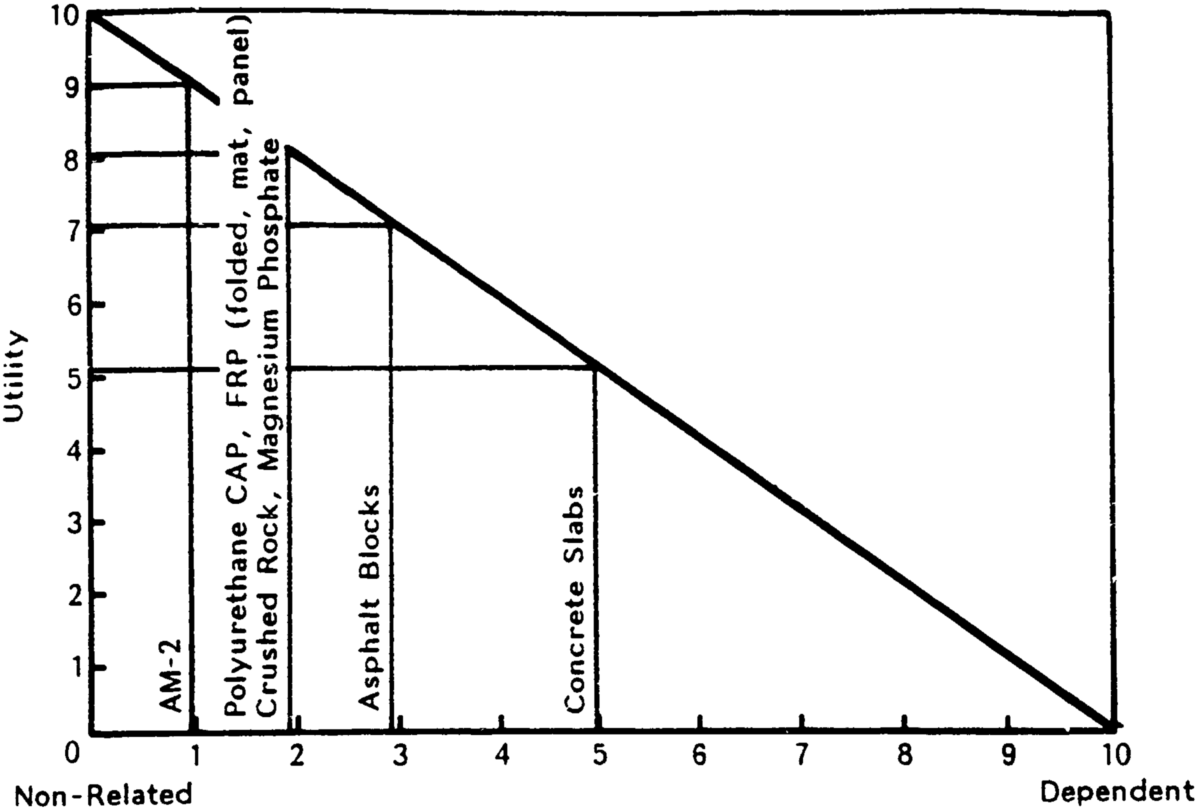


Figure 33. OPERATIONAL for SN2.
(Under wide temperature range)

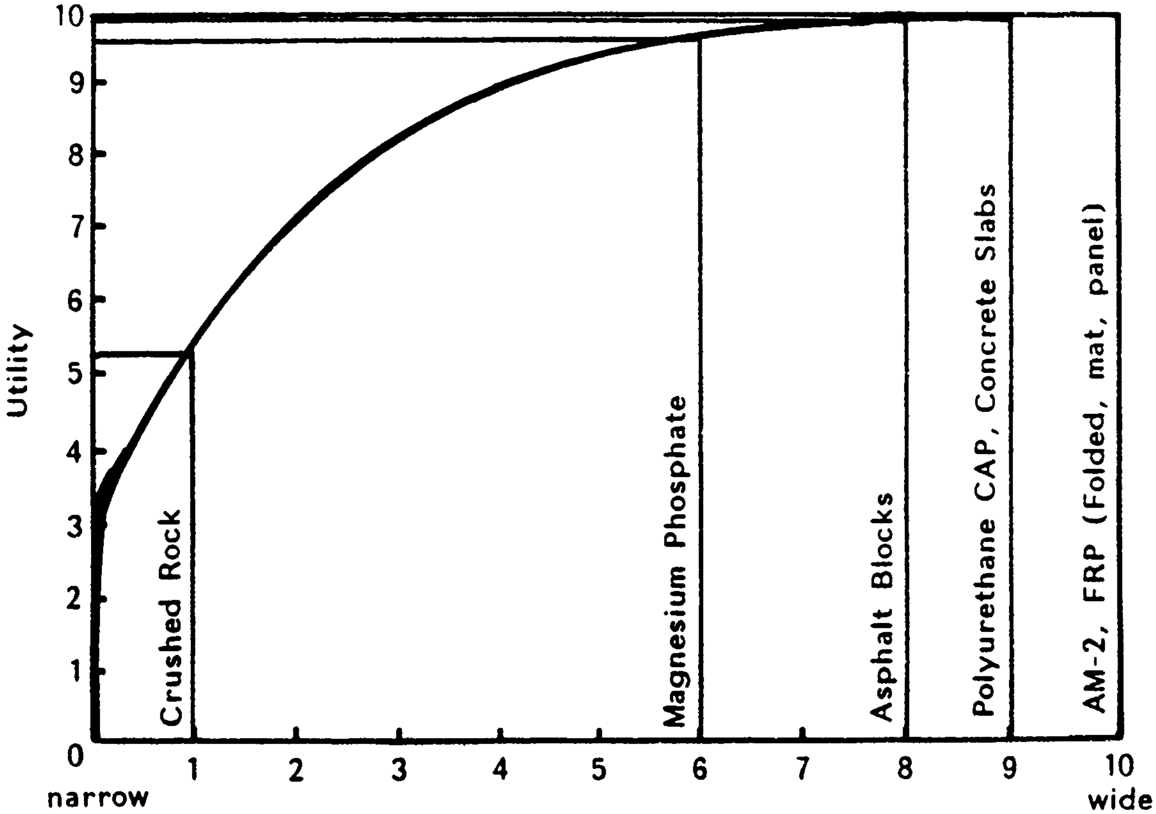


Figure 34. EQUIPMENT INTENSIVENESS for SN2.

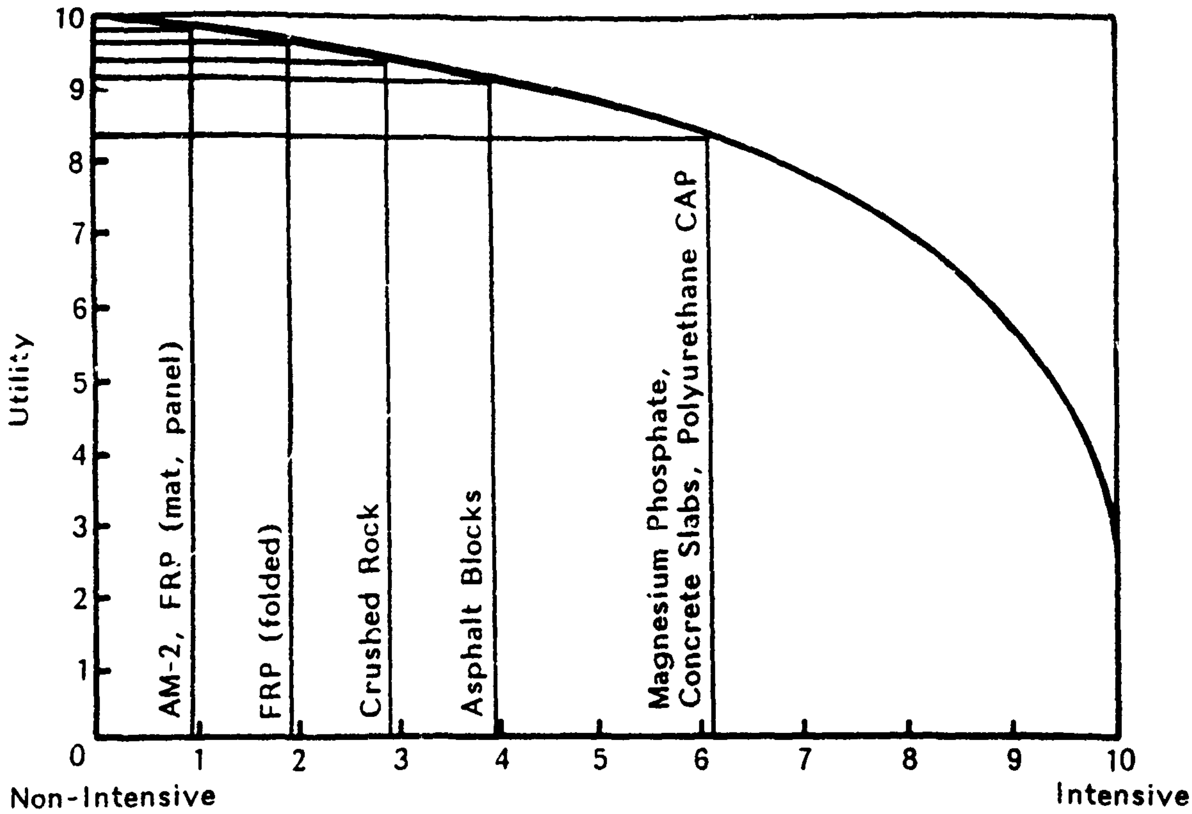


Figure 35. MAINTENANCE DIFFICULTY for SN2.
(Need for Maintenance and Amount of Difficulty)

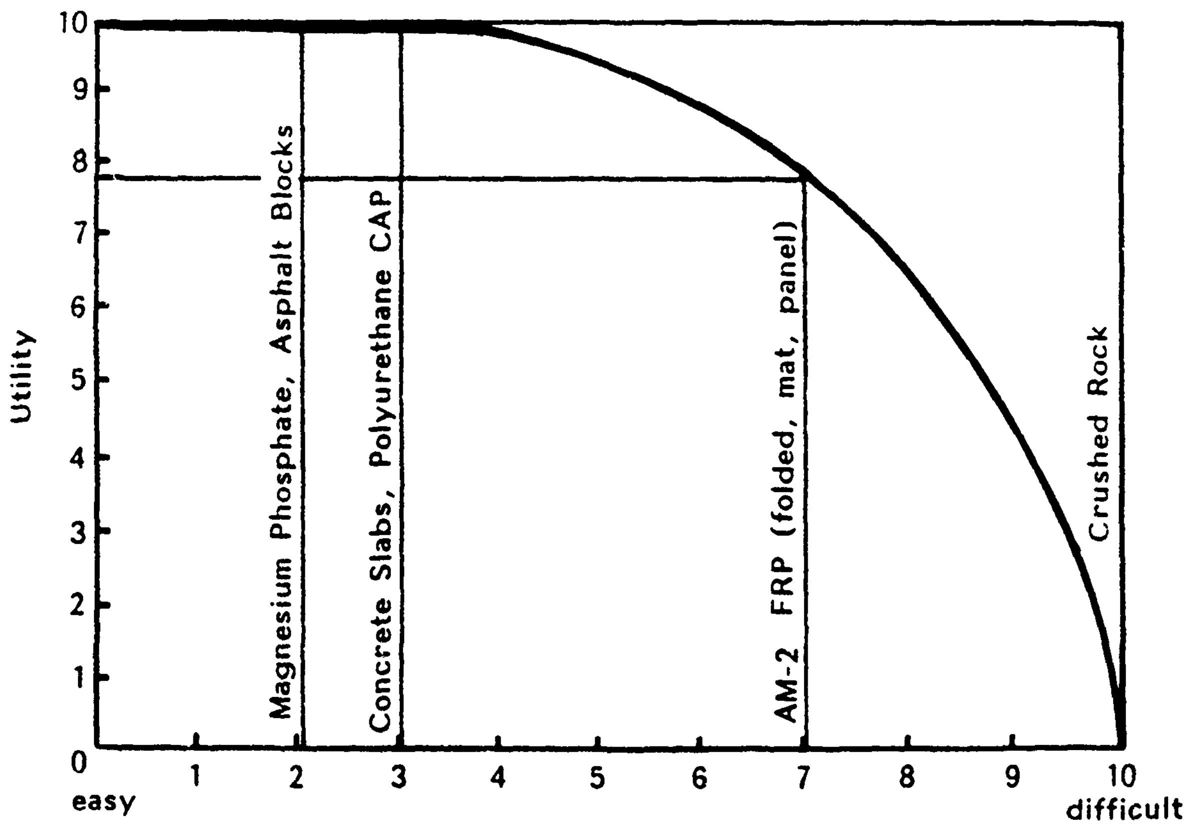


Figure 36. OPERATIONAL for SN2.
(Types of Aircraft Supported)

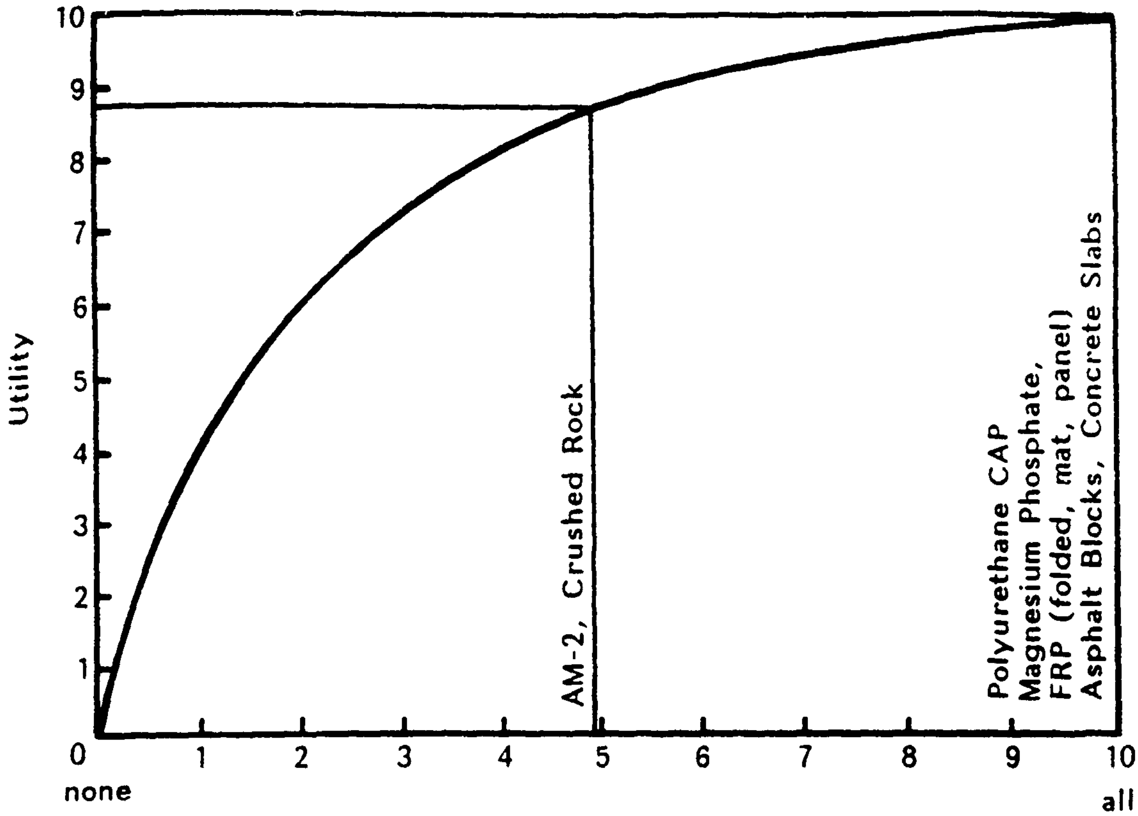


Figure 37. SHELF LIFE (YEARS) for SN2.

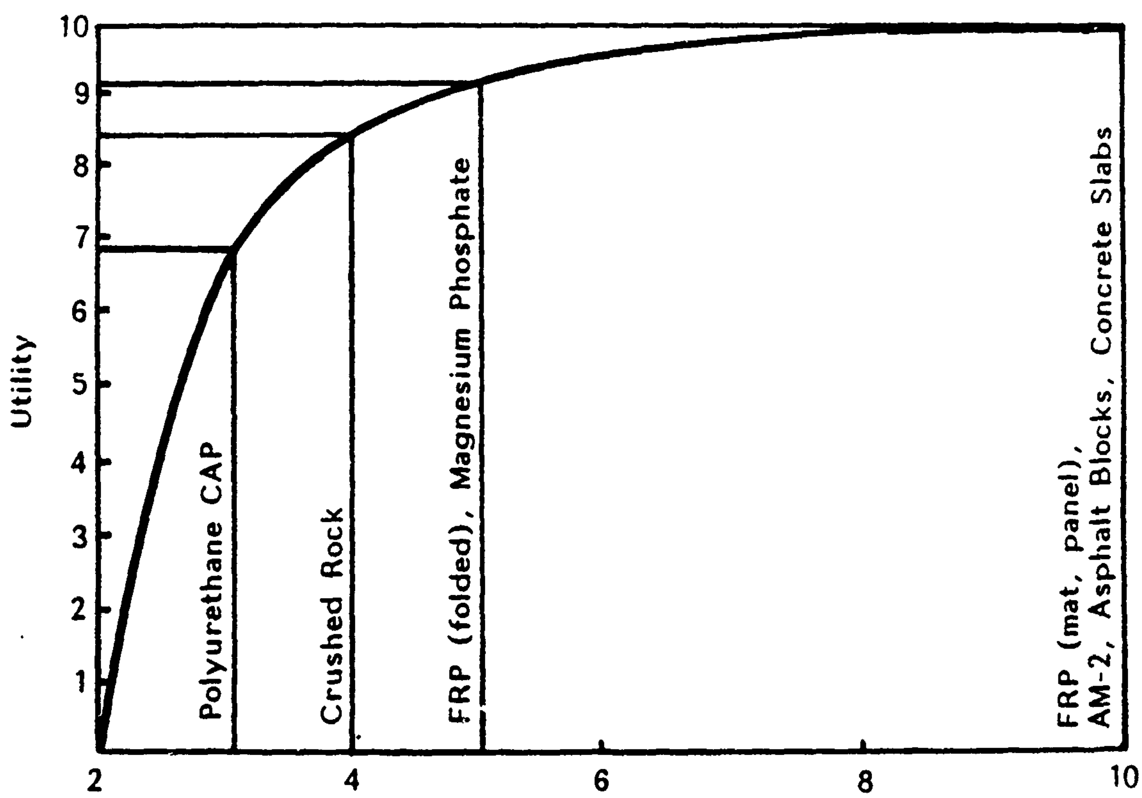


Figure 38. COST ($/sq. ft.) for SN2.

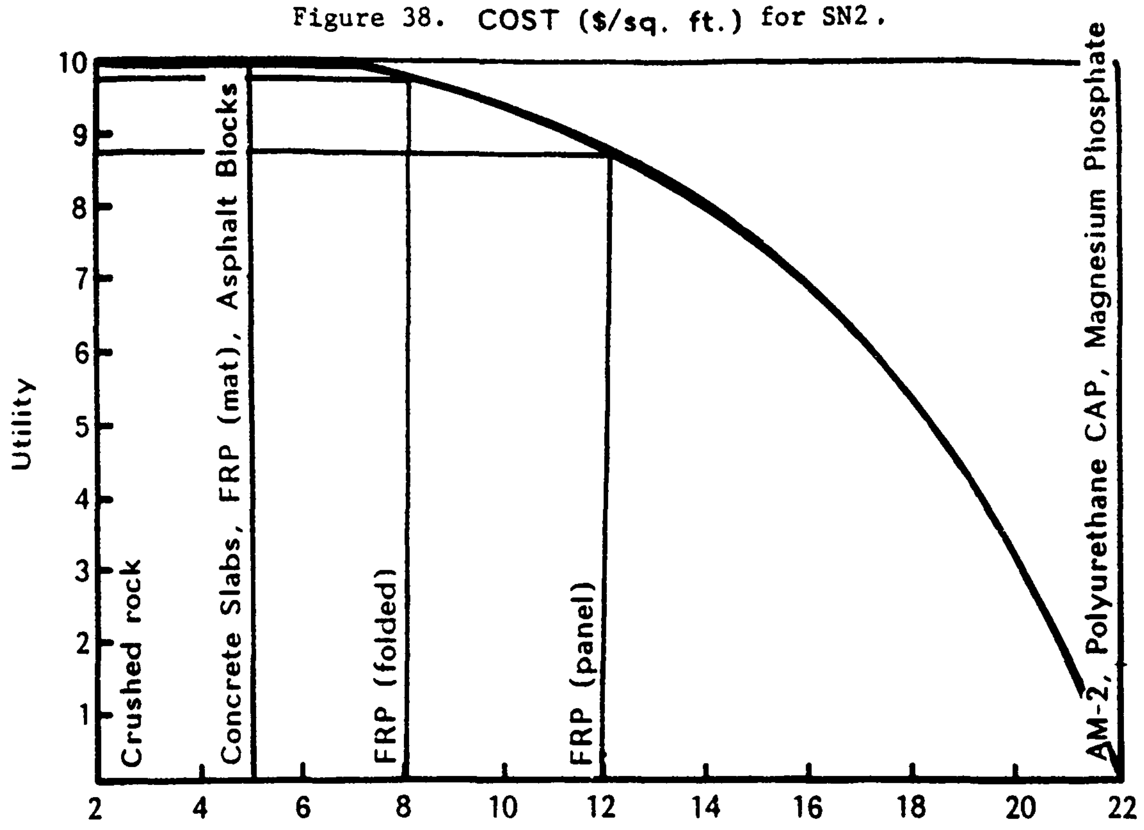


Figure 39. STORAGE for SN2.

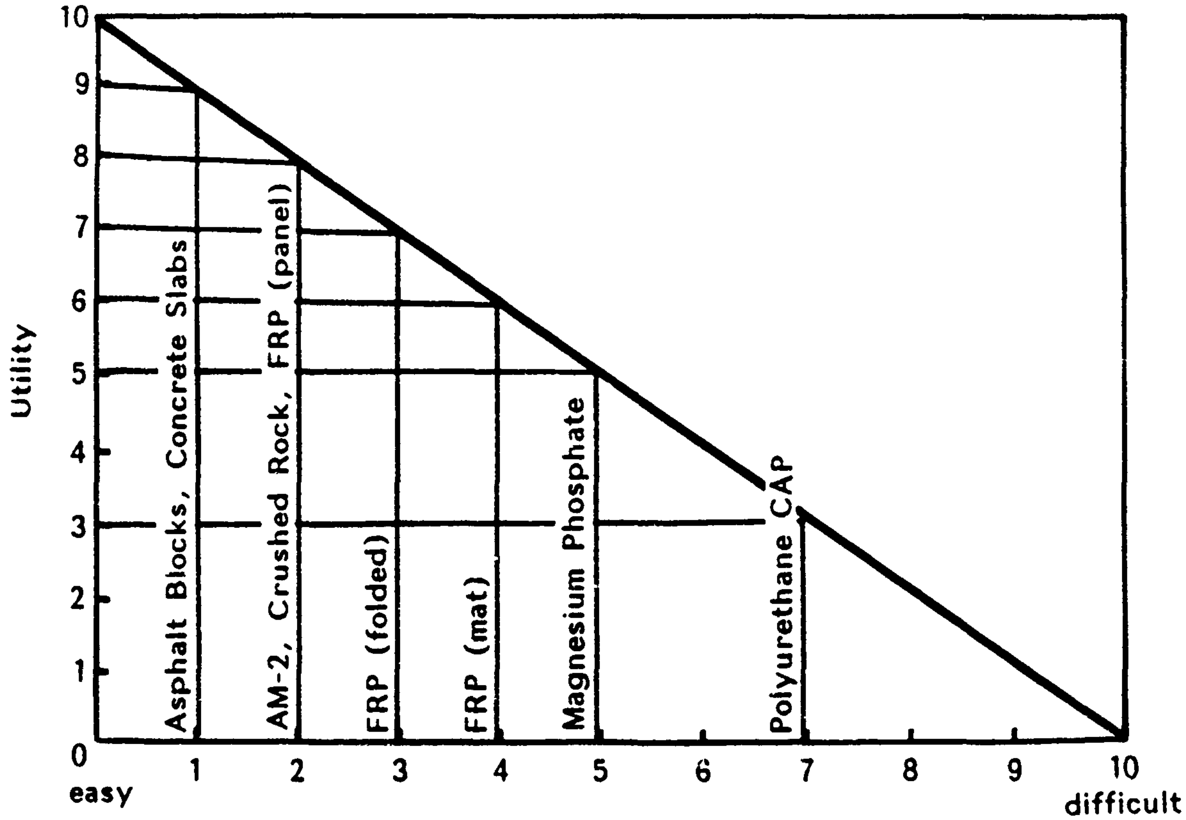


Figure 40. UTILITY for SN2.

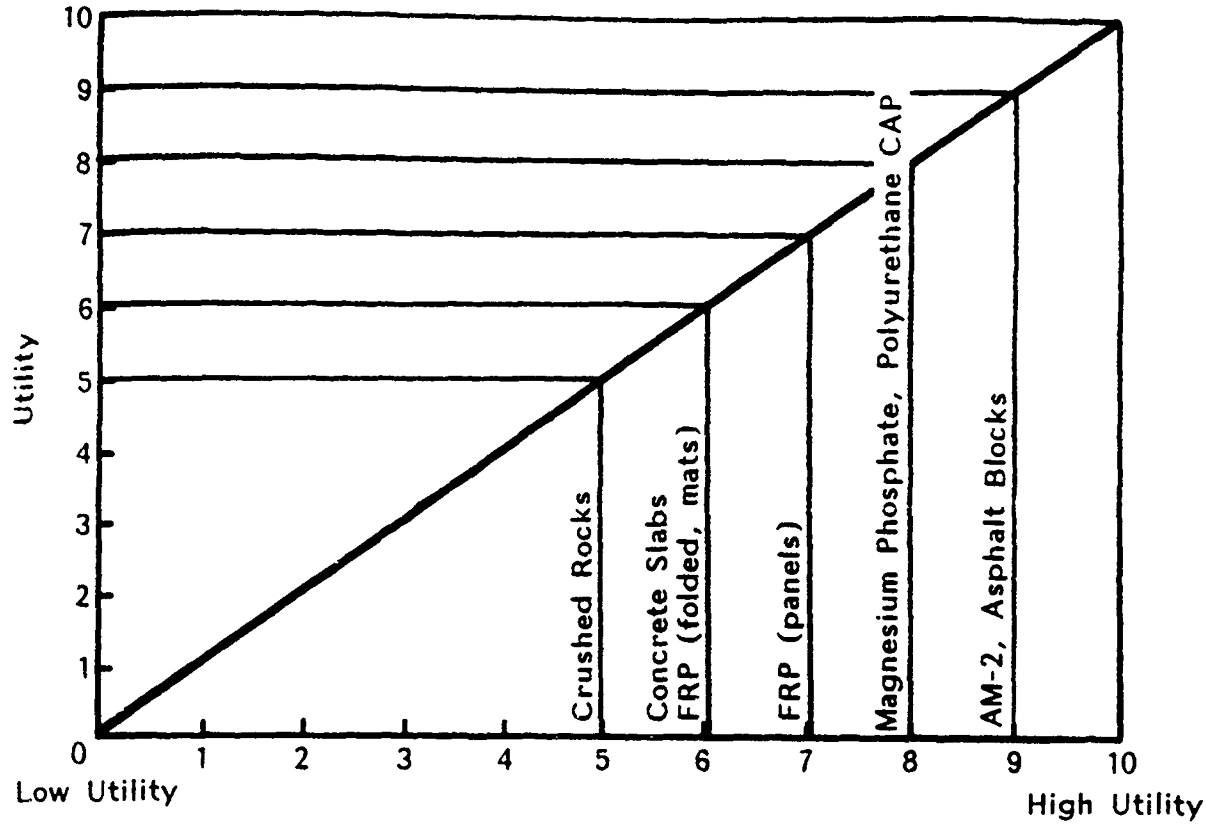


Figure 41. NEED FOR DEDICATED EQUIPMENT for SN2.
(Different Types of Dedicated Equipment)

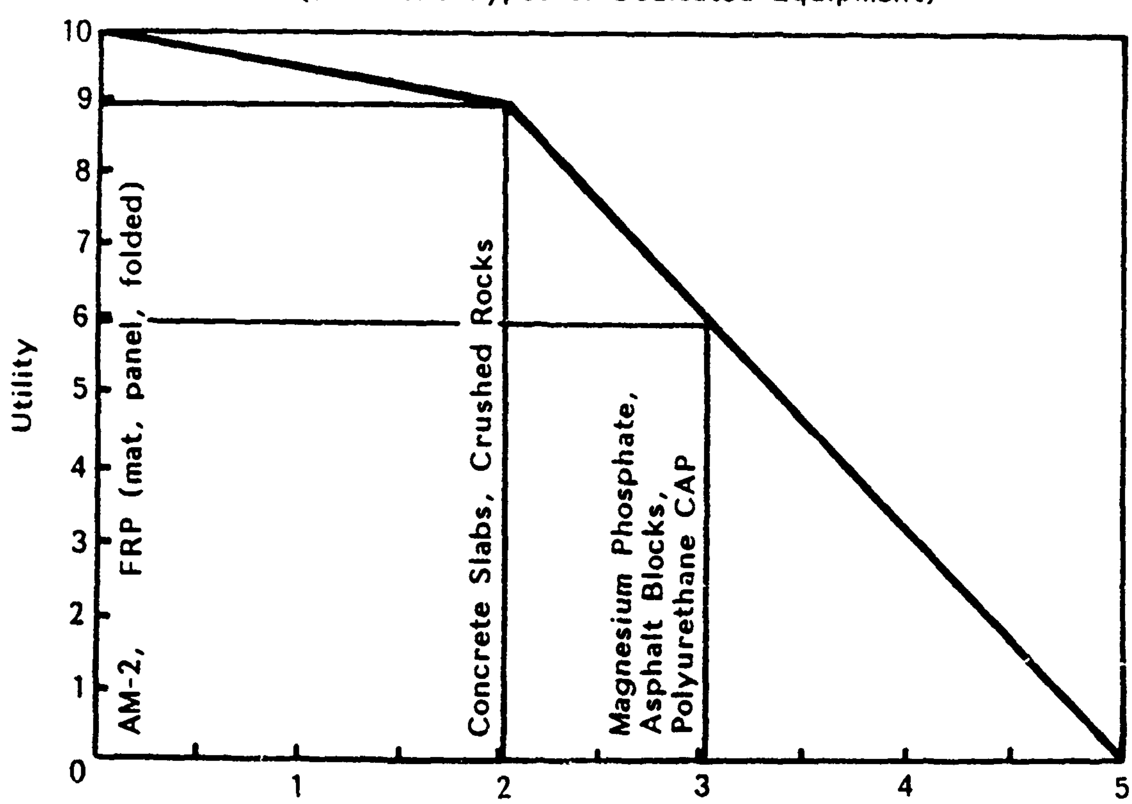


Figure 42. PEACE TIME USAGE for SN2.

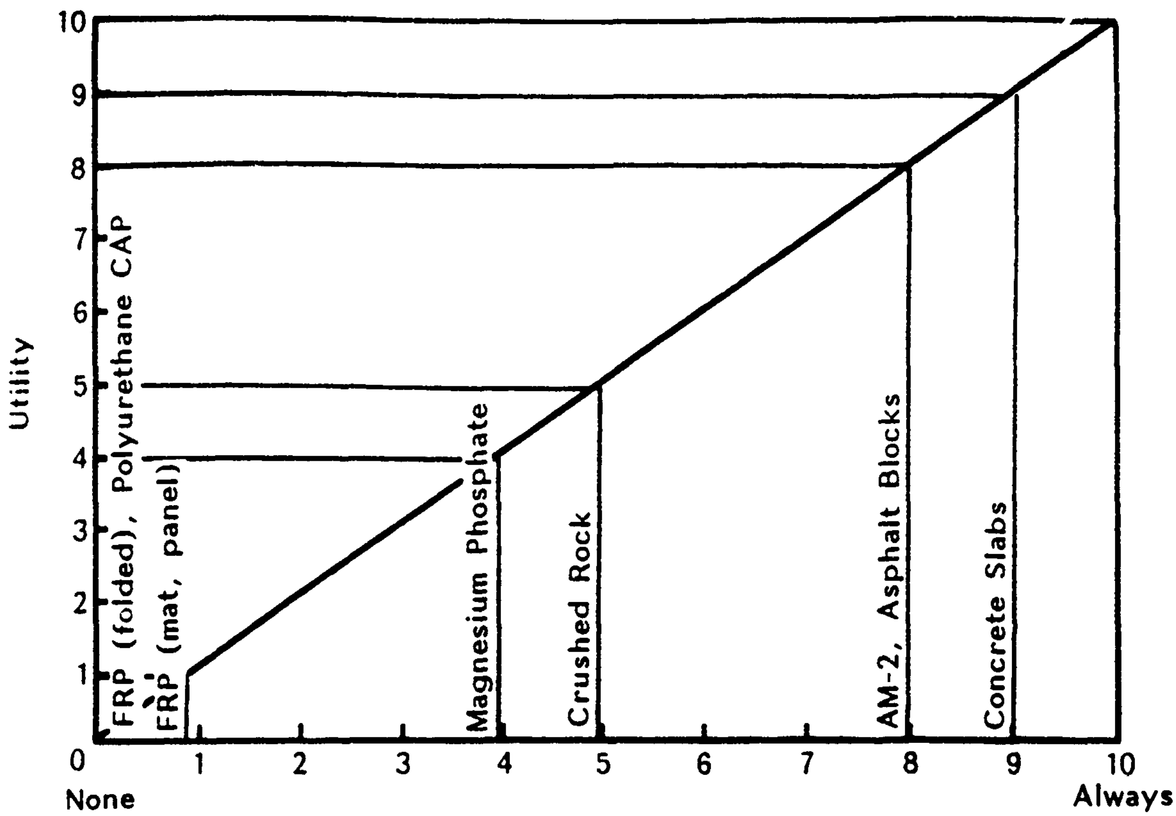


Figure 43. INITIAL REPAIR TIME for SN3.
(hours)

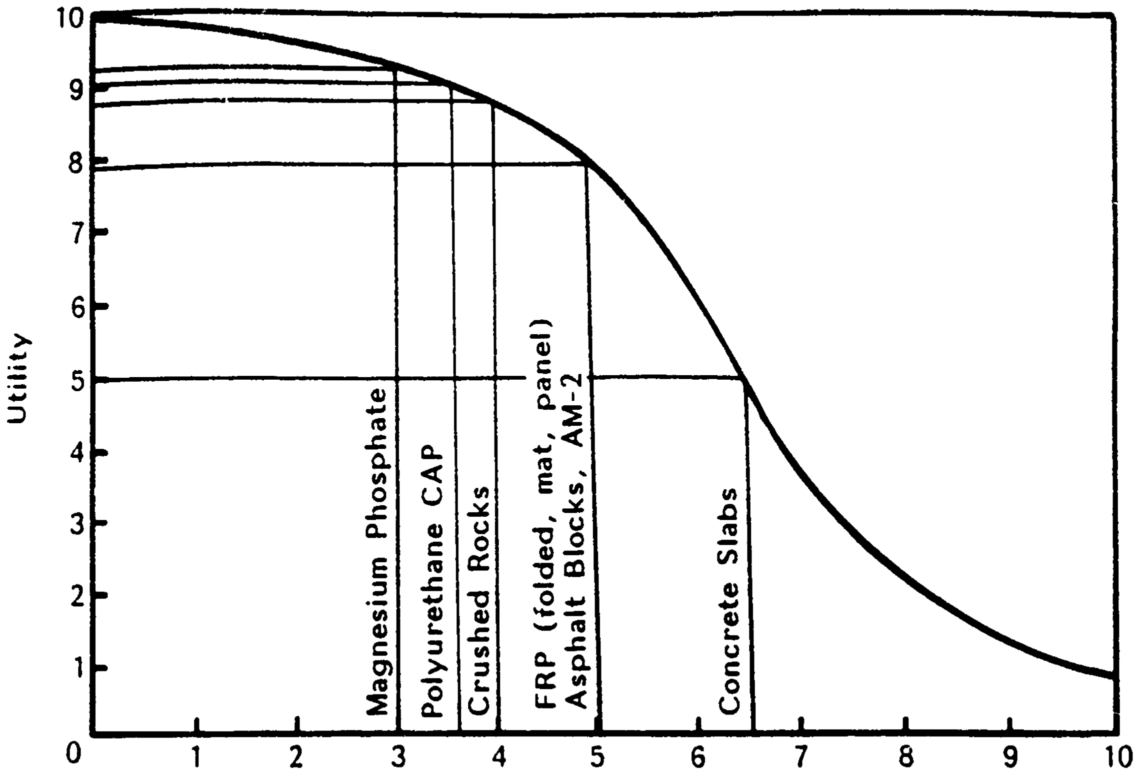


Figure 44. STRUCTURAL STRENGTH for SN3.
(Traffic supported after initial and in between repairs)

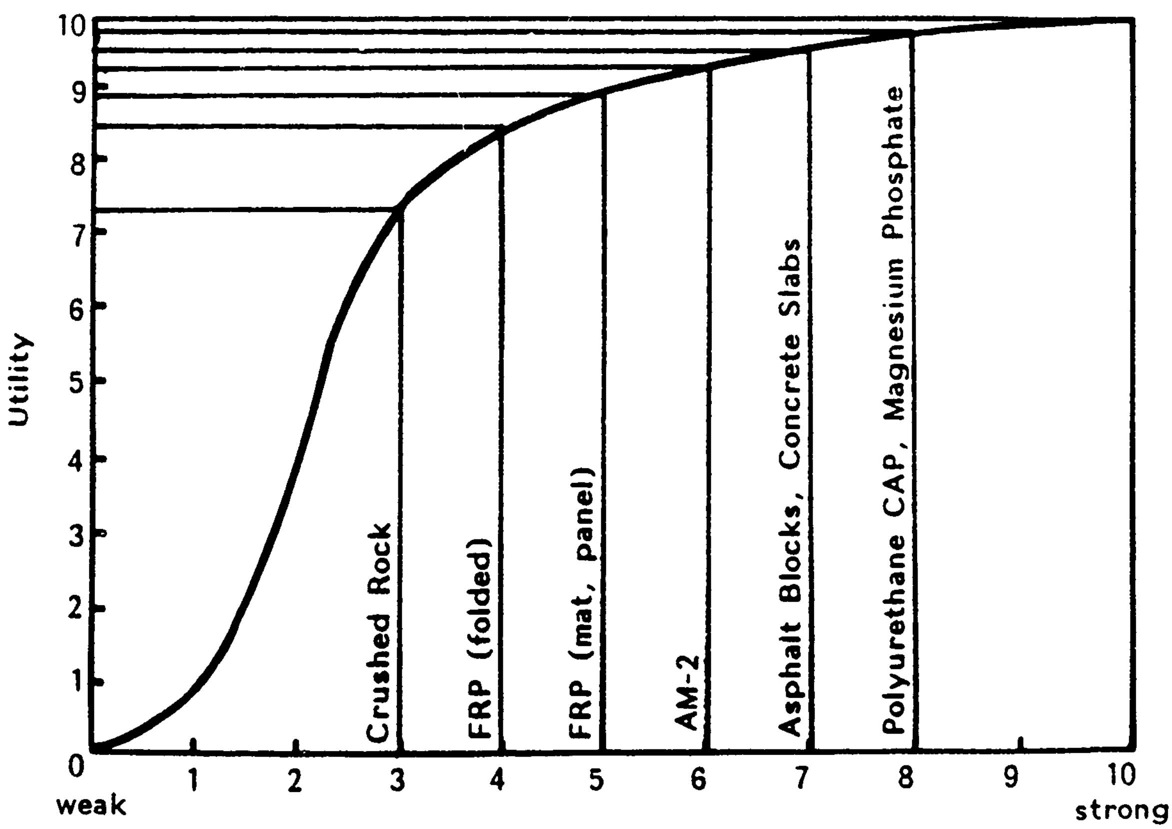


Figure 45. COMPLEXITY for SN3.

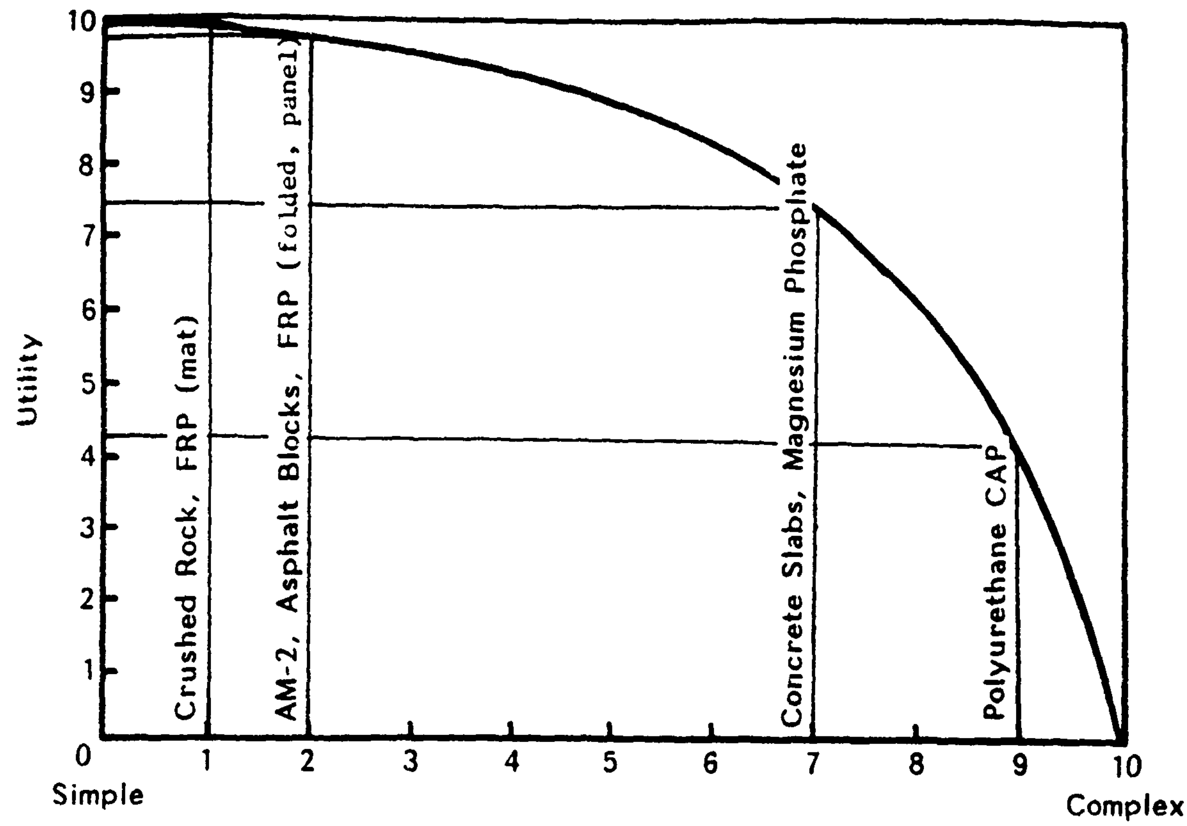


Figure 46. LABOR INTENSIVENESS for SN3.

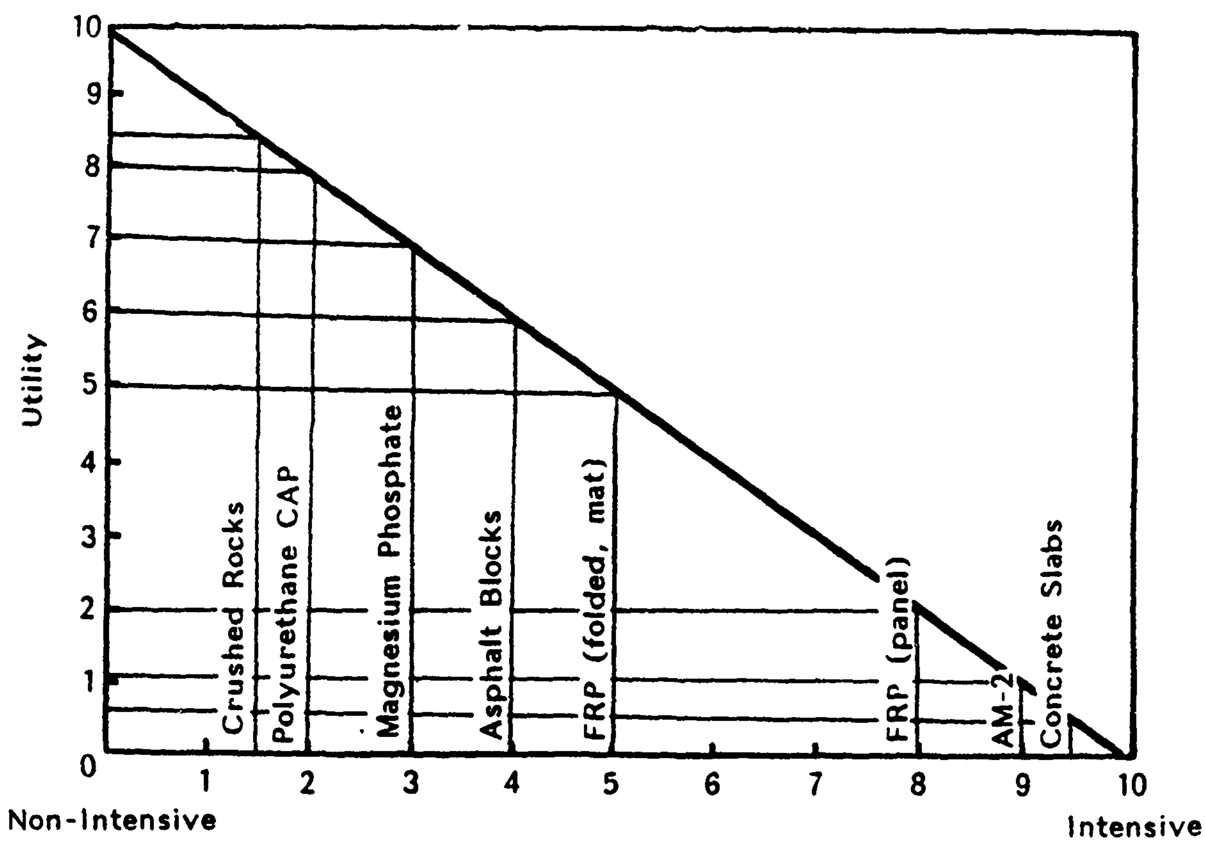


Figure 47. DEPENDENCY for SN3.
(On Prior Procedures)

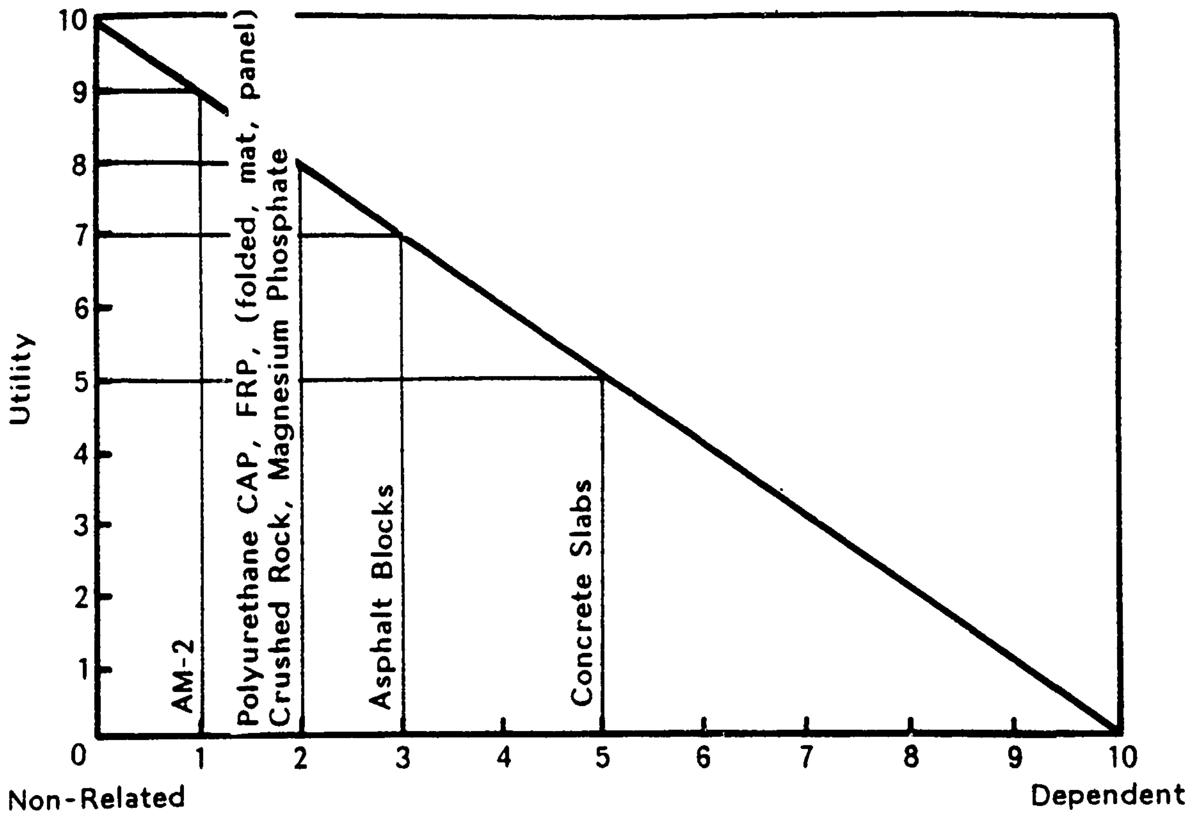


Figure 48. OPERATIONAL for SN3.
(Under Wide Temperature Range)

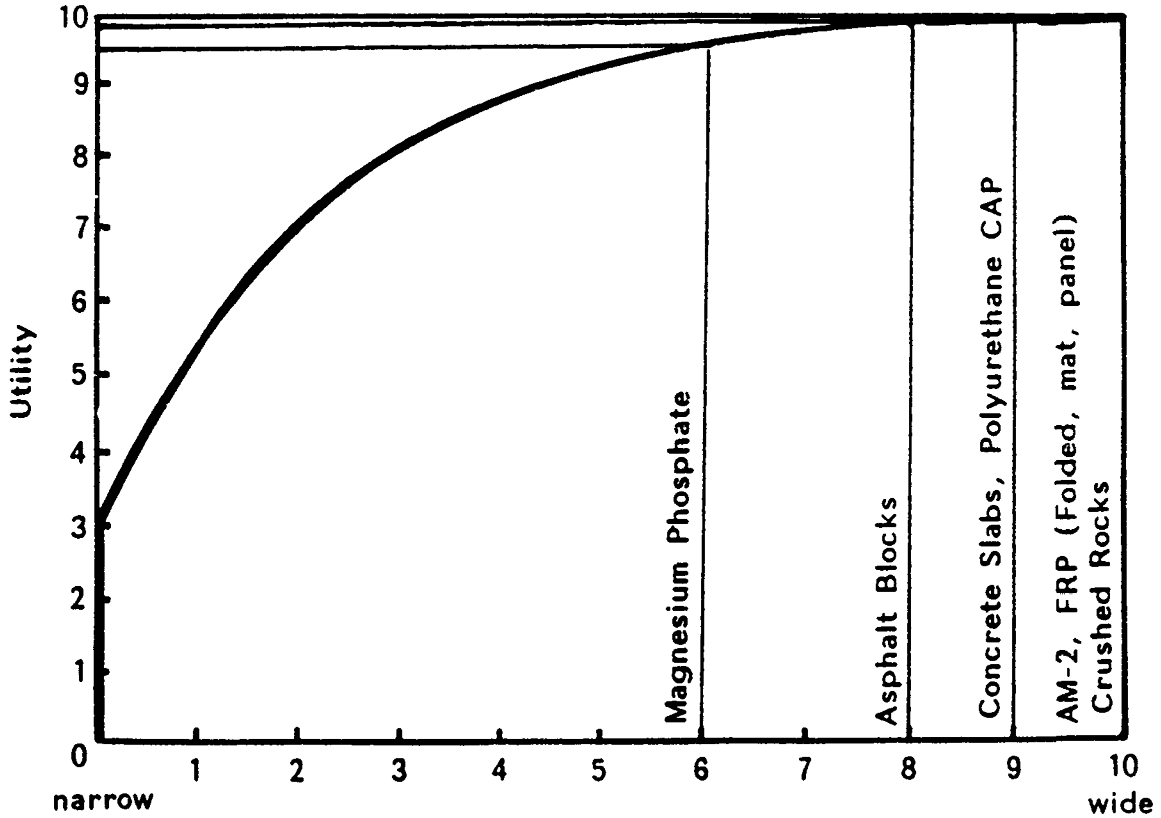


Figure 49. EQUIPMENT INTENSIVENESS for SN3.

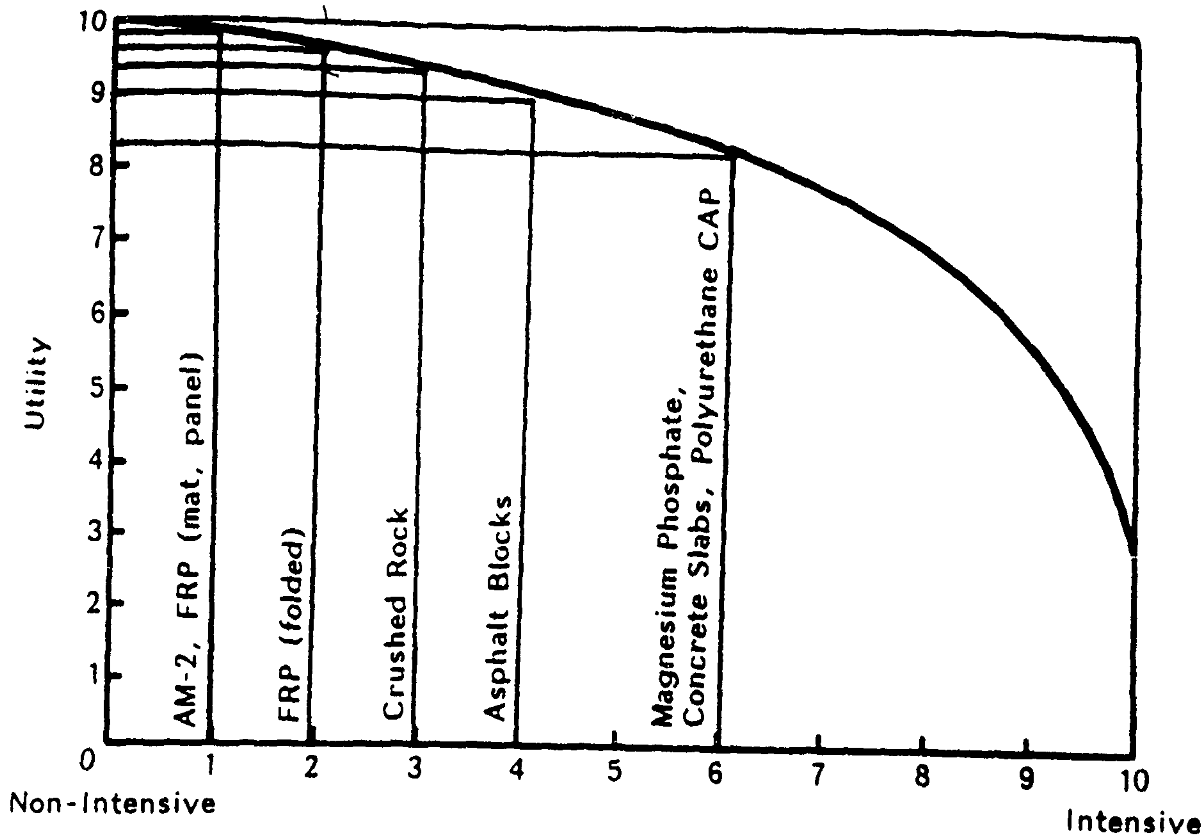


Figure 50. MAINTENANCE DIFFICULTY for SN3.
(Need for maintenance and amount of difficulty)

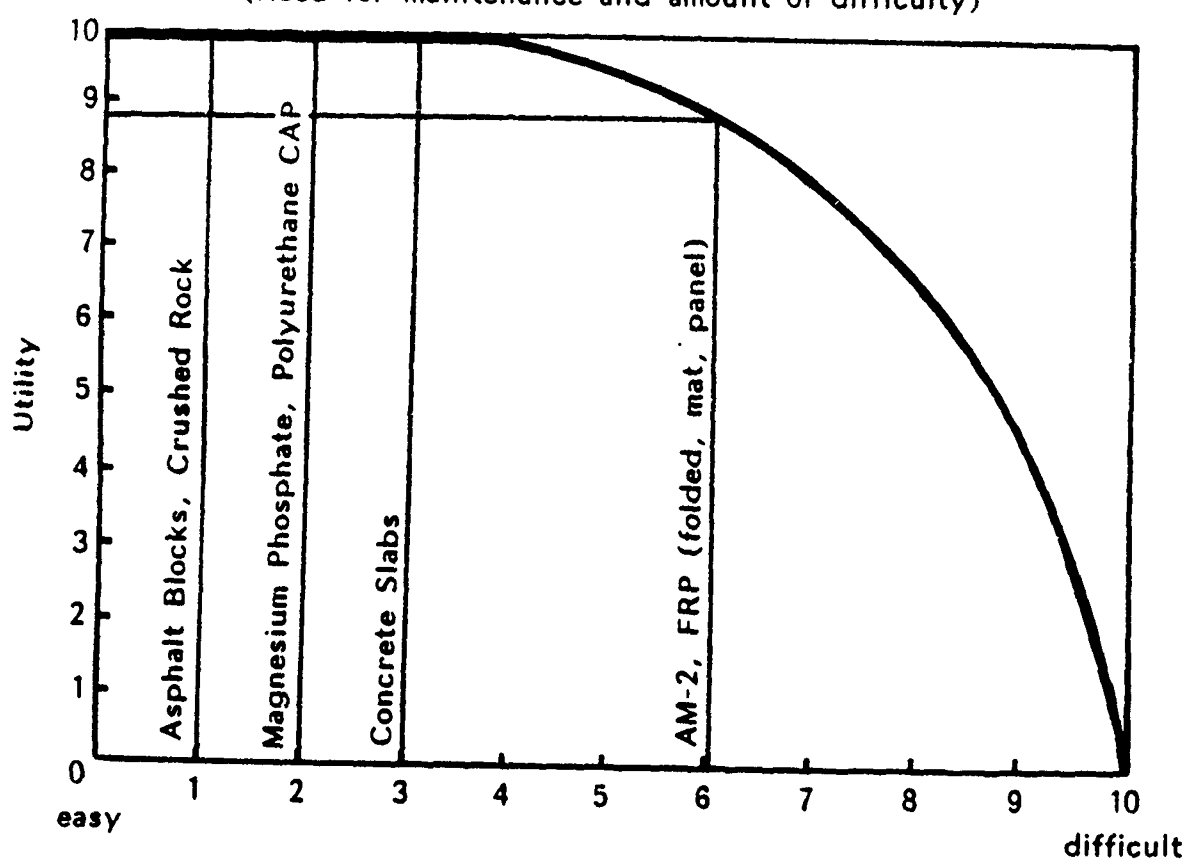


Figure 51. OPERATIONAL for SN3.
(Types of Aircraft Supported)

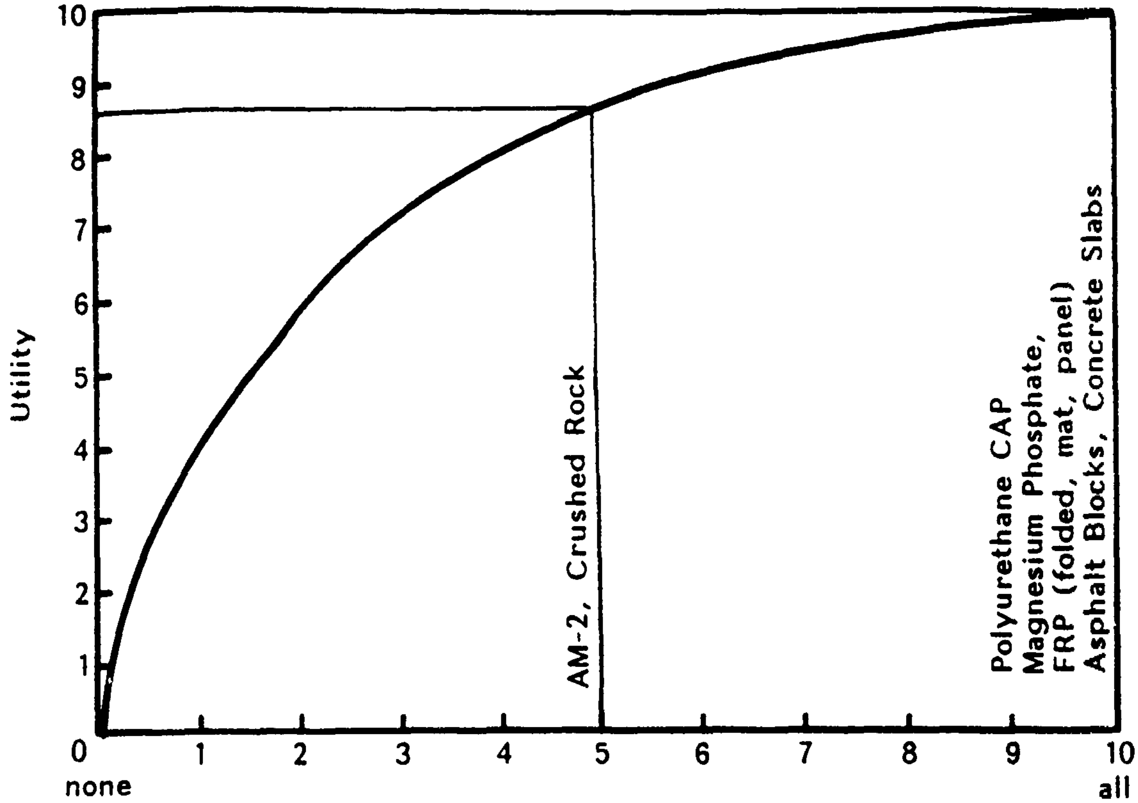


Figure 52. SHELF LIFE (YEARS) for SN3.

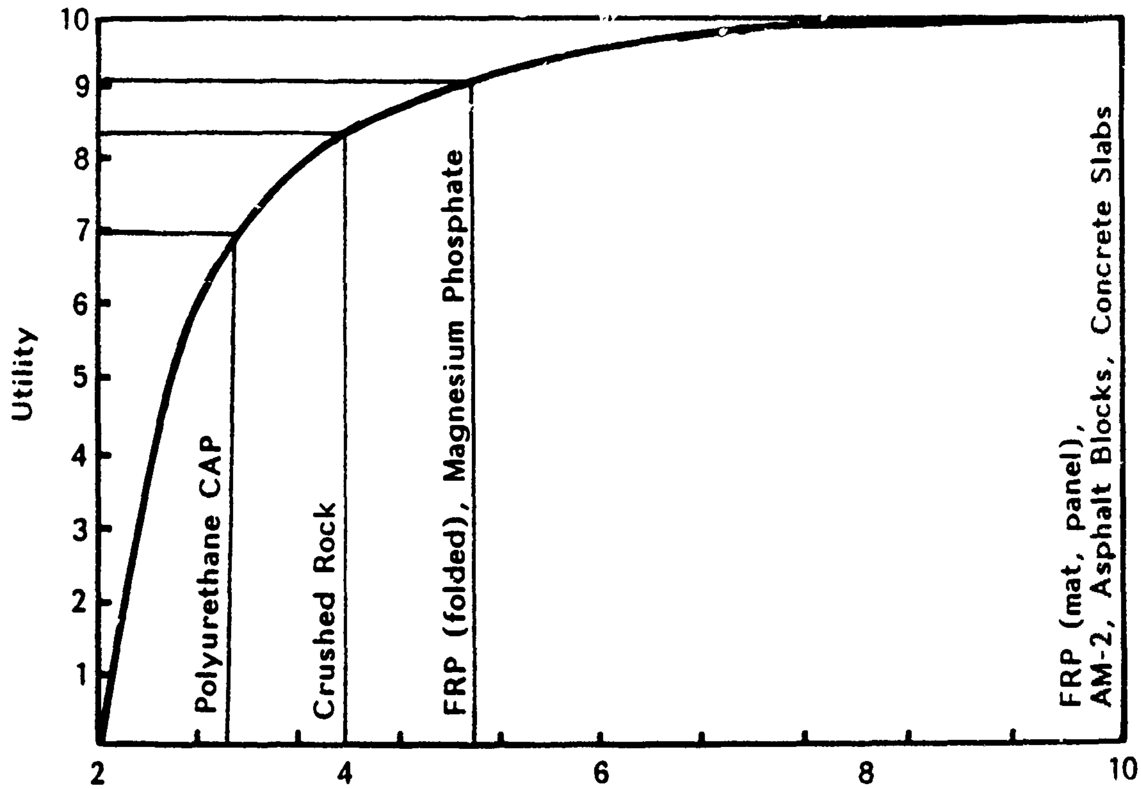


Figure 53. COST ($/sq. ft.) for SN3.

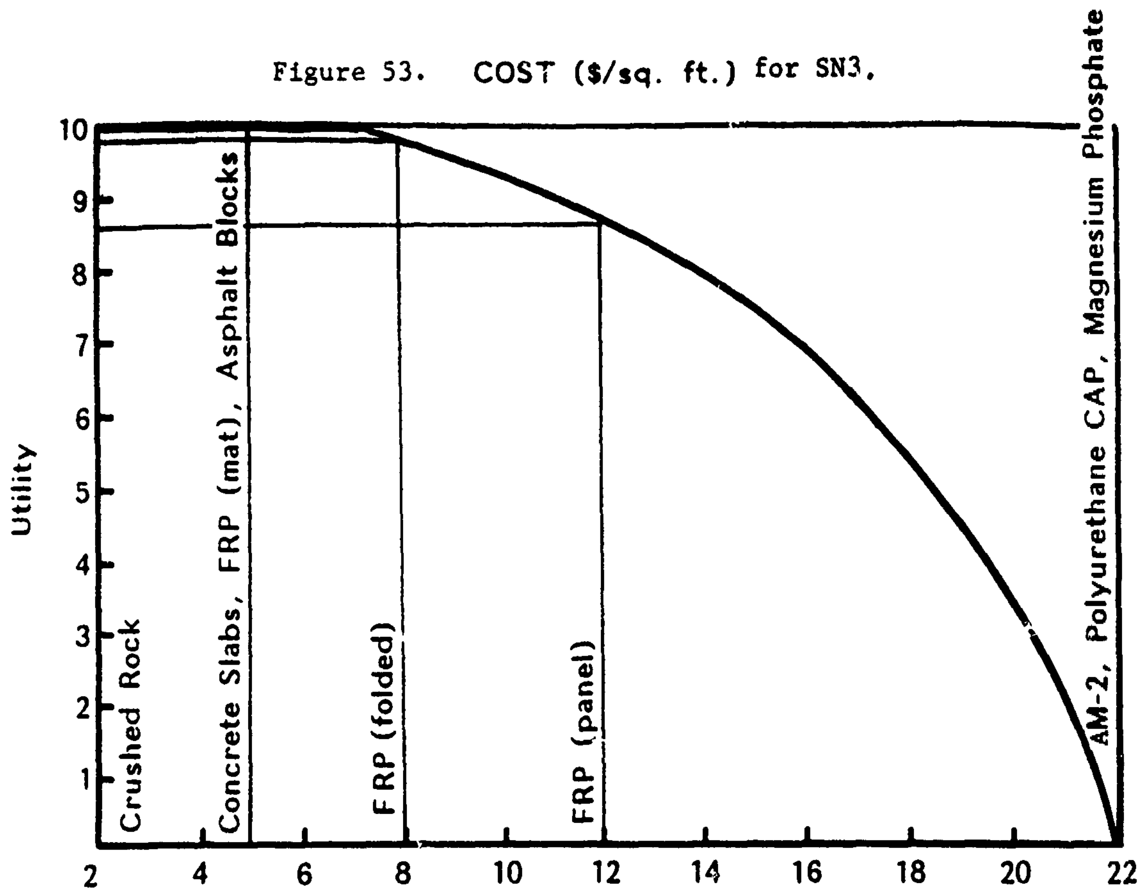


Figure 54. STORAGE for SN3.

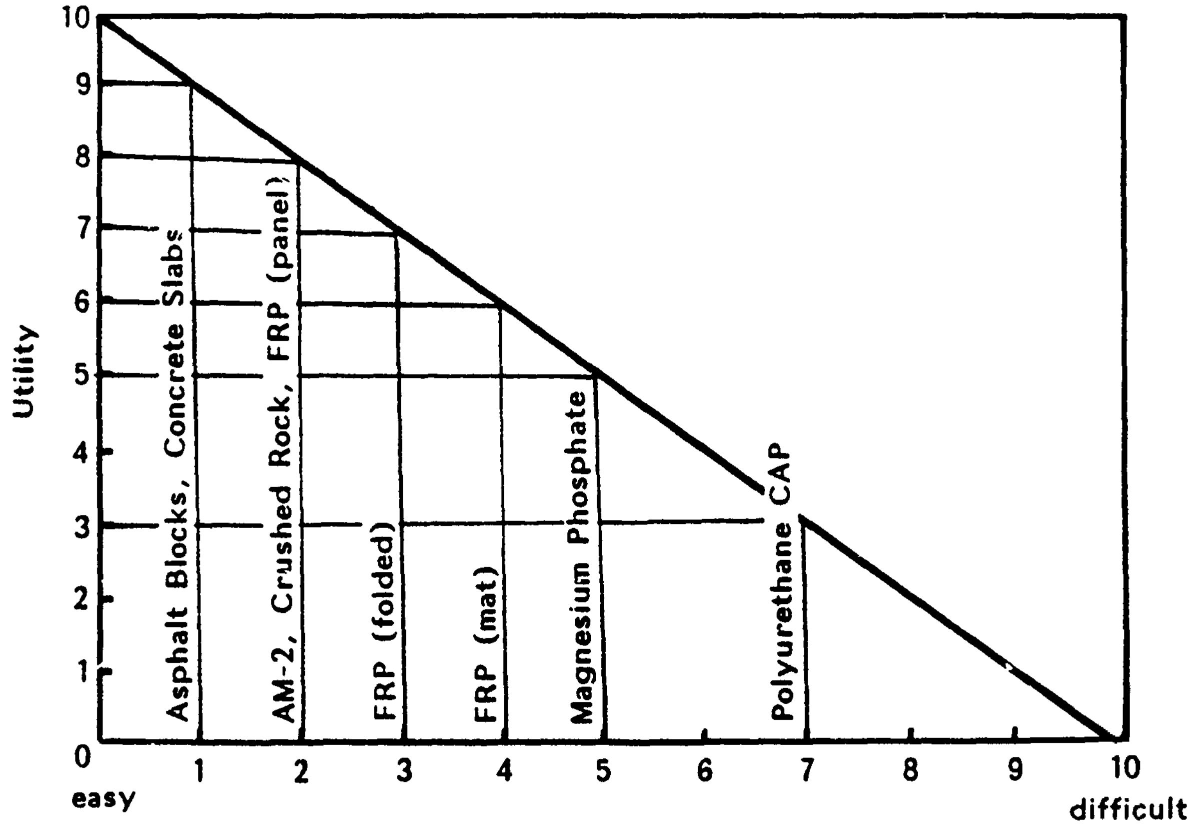


Figure 55. UTILITY for SN3.

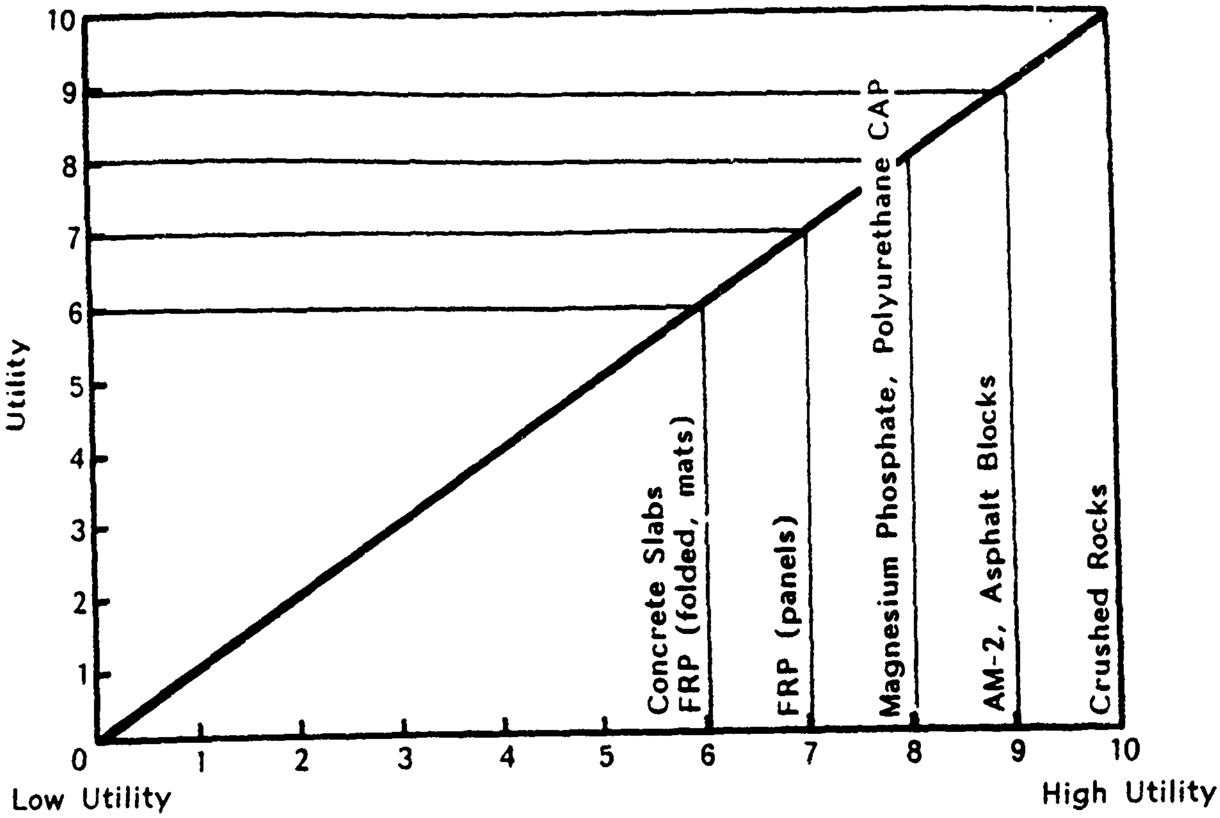


Figure 56. NEED FOR DEDICATED EQUIPMENT for SN3.
(Different Types of Dedicated Equipment)

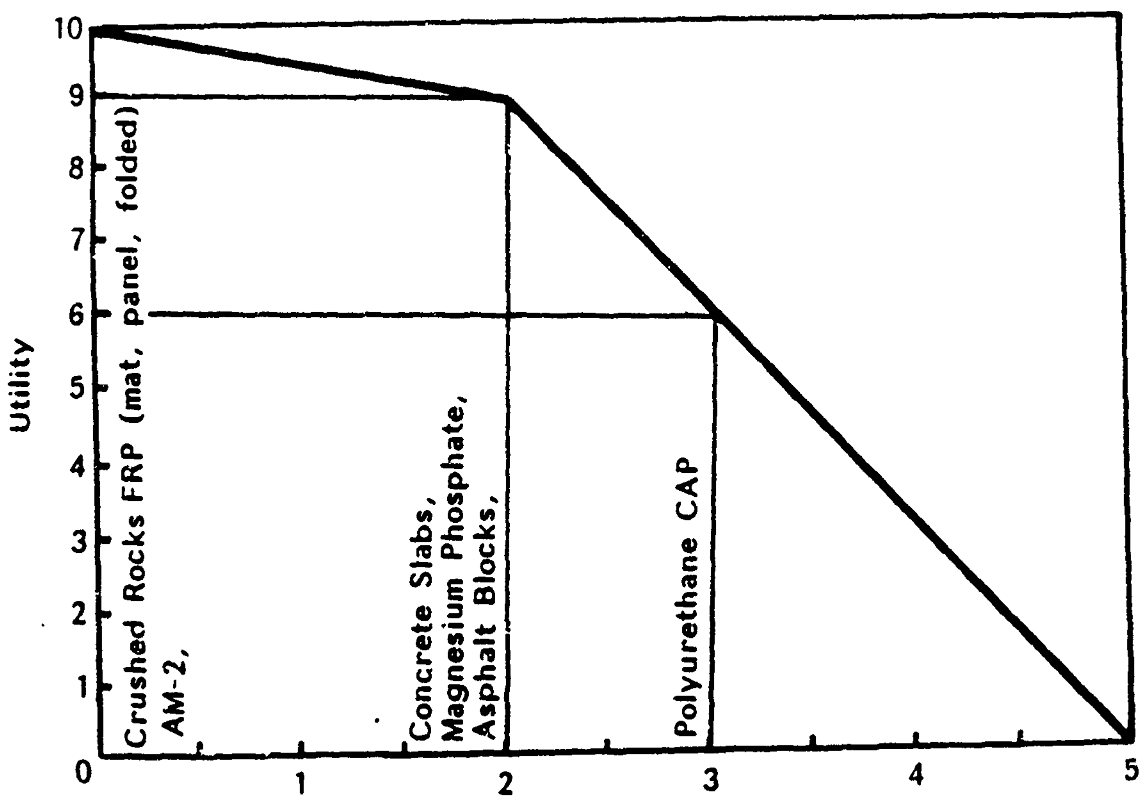
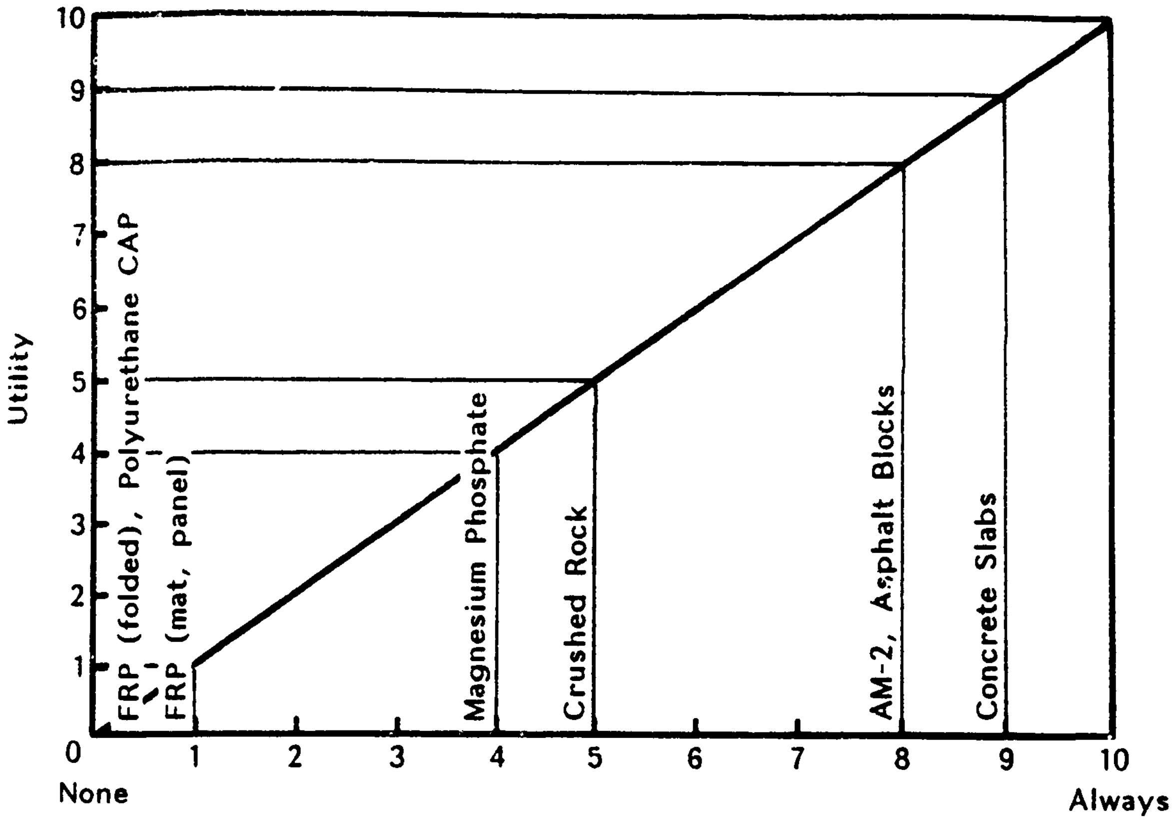


Figure 57. PEACE TIME USAGE for SN3.



Appendix A

USING DELPHI ANALYSIS AND BRAINSTORMING AS PROBLEM SOLVING TECHNIQUES FOR RAPID RUNWAY REPAIR (RRR)

DELPHI TECHNIQUE

The criteria defined in the rapid runway repair (RRR) systems analysis was ranked using the Delphi technique. This technique is similar to brainstorming, except that the people involved are not physically together at a meeting place, but instead work separately. The first step is for the coordinator to select a panel of experts with some background in the problem area. The coordinator then prepares a questionnaire that is relevant to the problem. The questionnaire is sent to each participant for answers. Upon receipt of the answers, the coordinator analyzes the results and determines the median and 50th percentile values. A second questionnaire (identical to the first) is then sent out asking the same questions, except this time the median and 50th percentile answers are shown next to each question. The participants are asked to reconsider each answer in view of the results from the first questionnaire. If their second response is outside the 50th percentile, they are asked to provide reasons for their answers. The answers to the questionnaire are again analyzed by the coordinator and the new median and 50th percentile values are calculated. A third questionnaire is sent out (showing the results of the second questionnaire) asking the participants to answer the questions taking into account the previous answers and arguments for or against specific questions. Again, if their answers fall outside the 50th percentile range, an explanation is required. This process continues until the coordinator feels that there is sufficient information to make a conclusion (usually four questionnaires). The results are summarized and presented. Tables A-1 to A-3 show the three questionnaires that were sent out in the RRR systems analysis.

BRAINSTORMING

This technique was used in the RRR systems analysis to generate a consensus of opinion for developing the three states of nature that the system may have to operate in. It was also used to develop the utility graphs and utility values for each alternative. Brainstorming brings together (physically) a group of knowledgeable people in a particular subject area and allows an interchange of ideas. It is used for planning, developing new proposals, and solving complex problems. The intent is to provide an atmosphere for free discussion with no inhibition of ideas. Following the brainstorming session, the coordinator examines the ideas and suggestions and selects the most reasonable and promising to be presented.

Table A-1.
Questionnaire 1 for RRR Delphi Analysis

Memo

From: L64/Chang

To: NCEL RRR Experts

You have been identified as a present/past rapid runway repair (RRR) expert. This is the first of three questionnaires that I am asking you to answer for my RRR systems analysis. Please rate the following criteria with respect to how important you feel each criterion is when selecting a rapid runway repair technique. Thanks for all the help.

Task: Rate and assign importance values for each criterion listed below.

Start by selecting the least important criterion and assign an importance value of 10. Then consider the next least important criterion and decide how much more important (if at all) it is than the least important. If four times as important then assign 40, if twice as important then assign 20, etc. Continue this process until all the criteria are rated.

Criteria	Value
Material cost	
Initial repair time	
Operational (under wide temperature range)	
Labor intensiveness	
Equipment intensiveness	
Complexity (level of skill required)	
Shelf life	
Peacetime usage	
Structural strength (sorties supported prior to first repair and in between repairs)	
Maintenance difficulty (difficulty to make repair after initial sorties)	

Note: Please make comments on the criteria (i.e., any criterion that should be added to the list, deleted from the list, etc.).

Additional Criteria	Value	Deletions
1.		
2.		
3.		

Comments:

Table A-2.
Questionnaire 2 for RRR Delphi Analysis

Memo

From: L64/Chang

To: NCEL RRR Experts

This is the second of three questionnaires that I am asking you to answer for my rapid runway repair (RRR) analysis. Please rerate the following criteria with respect to how important you feel each criterion is when selecting a RRR technique. I have compiled the last answers given and calculated the median and the 50th percent majority opinions. These figures are shown next to each criterion. If your second answer is outside the 50th percent majority, please provide reasons for your answers. Thanks for all the help.

Task: Rate and assign importance values for each criterion listed below.

Start by selecting the least important criterion and assign an importance value of 10. Then consider the next least important criterion and decide how much more important (if at all) it is than the least important. If four times as important then assign 40, if twice as important then assign 20, etc. Continue this process until all the criteria are rated. If your answer is outside the 50th percentile, please provide reasons.

	50th Percentile			
Criteria	Low	Median	High	Your 2nd Rating
Material cost	15	25	30	
Initial repair time	50	70	100	
Operational (under wide temperature range)	40	40	50	
Labor intensiveness	40	45	60	
Equipment intensiveness	40	48	60	
Complexity (level of skill required)	40	60	70	
Shelf life	30	30	40	
Peacetime usage	10	10	10	
Structural strength (sorties supported prior to first repair and in between repairs)	30	45	80	
Maintenance difficulty (difficulty to make repair after initial sorties)	30	48	60	

Reasons:

Table A-3. Questionnaire 3 for RRR Delphi Analysis

Memo

From: L64/Chang

To: NCEL RRR Experts

This is the third and final questionnaire that I am asking you to answer for my rapid runway repair (RRR) analysis. Please rerate the following criteria with respect to how important you feel each criterion is when selecting a RRR technique. I have compiled the last answers given and calculated the median and the 50th percent majority opinions. These figures are shown next to each criterion along with arguments against the majority opinions. If your third answer is outside the 50th percent majority, please provide reasons for your answers. Thanks for all the help.

Task: Rate and assign importance values for each criterion listed below.

Start by selecting the least important criterion and assign an importance value of 10. Then consider the next least important criterion and decide how much more important (if at all) it is than the least important. If four times as important then assign 40, if twice as important then assign 20, etc. Continue this process until all the criteria are rated. If your answer is outside the 50th percentile, please provide reasons

	50th Percentile			
Criteria	Low	Median	High	Your 2nd Rating
Material cost	20	20	25	
Initial repair time	70	83	100	
Operational (under wide temperature range)	40	43	50	
Labor intensiveness	40	55	60	
Equipment intensiveness	40	48	50	
Complexity (level of skill required)	45	60	70	
Shelf life	30	30	30	
Peacetime usage	10	10	10	
Structural strength (sorties supported prior to first repair and in between repairs)	40	55	70	
Maintenance difficulty (difficulty to make repair after initial sorties)	30	48	60	

Arguments:

1. Peacetime use 20 - If peacetime use is available, then it cuts down on dependence of other factors such as shelf life, complexity (workers will already be experienced).

2. Material cost 10 - Cost is inconsequential compared to aircraft cost.

3. Equipment intensiveness 70 - Equipment intensiveness is extremely important in Marine Corps and Navy, such as Kefluvik, where additional equipment may be needed.

4. Complexity 90 - In an emergency, may have only cooks and clerks available.

5. Shelf Life 100 - If too short, you can be assured material will be no good when needed (such as life boats during the WWII Wolf Pack Submarine attacks).

Reasons your answer is below 50% majority opinion:

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